AN ADVANCED EVALUATION OF PROHEXADIONE-CALCIUM ON APPLE, PEAR, PLUM AND NECTARINE TREES

BY

JACOBUS JOHANNES MEINTJES

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Supervisor:	Prof. K.I. Theron	Dept. of Horticultural Science University of Stellenbosch
Co-supervisor:	Prof. P.J.C. Stassen	Dept. of Horticultural Science University of Stellenbosch

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DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously, in its entirety or in part, submitted it to any university for a degree.

'N GEVORDERDE EVALUERING VAN PROHEKSADIOON-KALSIUM OP APPEL-, PEER-, PRUIM- EN NEKTARIENBOME

OPSOMMING

Die beheer van oormatige lootgroei is van kardinale belang in vrugtebome. Tans word die plantgroeireguleerder proheksadioon-kalsium (P-Ca) gebruik om die lootgroei van appels te beheer in die Verenigde State van Amerika en sekere lande in Europa. Die effek van P-Ca op lootgroei en vruggrootte is in proewe op appels (*Malus domestica* B.), pere (*Pyrus cummunis* L.), pruime (*Prunus salicina* L.) en nekatriens (*Prunus persica* L.) geëvalueer. Aangesien lootgroei inhibisie moontlik vruggroei kan vesnel, is 'n literatuurstudie oor die vruggroei van kern-en steenvrugte gedoen. Die ontwikkelling van gesplete pit by steenvrugte ('n fisiologiese defek geassosieer met versnelde vruggroei) is ook ondersoek.

Gedurende die 2001 / 2002 seisoen is P-Ca in twee afsonderlike proewe in die Villiersdorp area van die Wes Kaap geëvalueer. Enkel en veelvuldige toedienings van verskeie konsentrasies P-Ca, met en sonder die benatter Dash®, is op 'Golden Delicious' en 'Granny Smith' bome toegedien. Een proef is herhaal gedurende die 2002 / 2003 seisoen.

In die 2001 / 2002 seisoen het die P-Ca behandelings in beide proewe die lootgroei van 'Golden Delicious' verminder. Die lootgroei van 'Granny Smith' is in beide proewe verminder waar P-Ca 3 of 4 keer toegedien is. Die vruggrootte van 'Golden Delicious', maar nie 'Granny Smith' nie, is in beide proewe deur die P-Ca verbeter. In die 2002 / 2003 seisoen kon die enkeltoedienings van P-Ca nie die lootgroei verminder van 'Golden Delicious' of 'Granny Smith' nie. 'Golden Delicious' is geoes voor enige inligting oor die vruggrootte ingesamel kon word. Weereens het P-Ca geen invloed op die vruggrootte van 'Granny Smith' gehad nie. Dash® het nie die effek van P-Ca verbeter nie.

In die 2002 / 2003 seisoen is proewe met P-Ca gedoen op 5 verskillende peer kultivars in die Wolsely area van die Wes Kaap. P-Ca is teen verskillende konsentrasies, met enkel en veelvuldige bespuitings toegedien en vergelyk met 'n ringelerings behandeling (2 weke na volblom). 'Early Bon Chretien', 'Rosemarie', 'Flamingo', 'Forelle' en 'Packham's Triumph' bome is gebruik en die benatter Dash® is by al die behandelings gevoeg

P-Ca toedienings het lootgroei verminder in 'Early Bon Chretien', 'Rosemarie', 'Flamingo', 'Forelle' en 'Packham's Triumph'. Ringelering kon slegs die lootgroei van 'Forelle' verminder. P-Ca het die vrugset van 'Early Bon Chretien', 'Rosemarie'en 'Forelle' verhoog. Die toename in vrugset het gelei tot 'n afname in die vruggrootte van 'Early Bon Chretien' en 'Rosemarie'. Ringelering het die vruggrootte van 'Flamingo' en 'Early Bon Chretien' verbeter. P-Ca het 'n afname in die hoeveelheid reproduktiewe knoppe in die volgende seisoen, van 'Packham's Triumph' en 'Forelle' veroorsaak. Ringelering het 'n toename in die hoeveelheid vegetatiewe knoppe in die volgende seisoen gehad vir al die kultivars, behalwe 'Packham's Triumph'.

Geduerende dieselfde seisoen is daar ook proewe gedoen op 'Pioneer' en 'Songold' pruime en 'May Glo' nektarienbome in onderskeidelik die Wemmershoek en Stellenbosch areas van die Wes Kaap. Bome is met enkel toedienings van verskillende konsentrasies P-Ca behandel en die benatter Dash® is by al die behandelings bygevoeg.

Die hoër dosisse P-Ca het die lootgroei van 'Pioneer' verminder. P-Ca kon slegs die aanvanklike lootgroei op 'Songold' verminder en kon nie lootgroei van 'May Glo' beperk nie. P-Ca het geen invloed op die vruggrootte van 'Pioneer', 'Songold' of 'May Glo' gehad nie. P-Ca het nie die voorkoms van gesplete-pit vererger nie.

Om saam te vat kan gesê word dat P-Ca lootgroei op appels en pere goed beperk teen die regte konsentrasies. Alhoewel P-Ca lootgroei suksesvol beheer het op 'Pioneer', moet daar meer werk gedoen word op steenvrugte.

SUMMARY

The control of excessive vegetative growth is important in deciduous fruit orchards. Currently the plant growth regulator prohexadione-calcium (P-Ca) is used to control apple shoot growth in the Untited States of America and some European countries. The effect of P-Ca on the shoot and fruit growth of apples (*Malus domestica* B.), pears (*Pyrus cummunis* L.), plums (*Prunus salicina* L.) and nectarines (*Prunus persica* L.) was evaluated. Inhibition of shoot growth can effect fruit growth. Therefore I did a literature review on the fruit growth of pome- and stone fruit. Split pit, a physiological disorder associated with an increased fruit growth rate in stone fruit, was also investigated.

During the course of the 2001 / 2002 season two trials were conducted in the Villiersdorp area of the Western Cape on 'Golden Delicious' and 'Granny Smith' apple trees. Single and multiple applications of P-Ca at different rates, with and without the surfactant Dash®, were applied. One of these trials was continued during the 2002 / 2003 season.

In the 2001 / 2002 season, P-Ca reduced shoot growth in both trials on 'Golden Delicious'. The shoot growth of 'Granny Smith' was reduced in both trials where P-Ca was applied three or four times. There was an improvement in the fruit size of 'Golden Delicious' in both trials, but there was no improvement in the fruit size of 'Granny Smith'. In the 2002 / 2003 season, the single P-Ca application did not reduce shoot growth. Unfortunately 'Golden Delicious' was harvested before any data were obtained. Once again P-Ca had no effect on the fruit size of 'Granny Smith'. Dash® did not improve the effect of P-Ca.

In the 2002 / 2003 season we replicated one trial on five different pear cultivars in the Wolsely area of the Western Cape. Single and multiple applications of P-Ca at different rates were compared to a girdling treatment (2 weeks after full bloom). 'Early Bon Chretien', 'Rosemarie', 'Flamingo', 'Forelle' and 'Packham's Triumph' pear trees were used and Dash® was added to all of the treatments.

P-Ca reduced shoot growth in all of the pear cultivars. Girdling reduced shoot growth only in 'Forelle'. P-Ca increased fruit set of 'Early Bon Chretien', 'Rosemarie' and 'Forelle', however, this was associated with a reduced fruit size of 'Early Bon Chretien' and 'Rosemarie'. Girdling did not increase fruit set, but increased fruit size of 'Flamingo' and 'Early Bon Chretien'. P-Ca reduced return bloom of 'Packham's Triumph' and 'Forelle', whereas girdling increased return bloom in all the cultivars except 'Packham's Triumph'.

In the 2002 / 2003 season, trials were also conducted on 'Pioneer' and 'Songold' plums and 'May Glo' nectarine in the Wemmershoek and Stellenbosch area of the Western Cape. Single applications at different rates of P-Ca were applied. Dash® was added to all of the treatments.

The higher rates of P-Ca reduced the shoot growth of 'Pioneer'. P-Ca only reduced shoot growth of 'Songold' initially and but did not reduce shoot growth of 'May Glo'. P-Ca had no influence on fruit size of 'Pioneer', 'Songold' or 'May Glo'. P-Ca did not aggravate the occurrence of split pit.

In conclusion, P-Ca reduced shoot growth in apples and pears when applied at the appropriate rates. Although P-Ca reduced shoot growth of 'Pioneer' plum, more research needs to be done on stone fruit to optimise timing and rate of P-Ca applications.

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CONTENTS

1. GENERAL INTRODUCTION

Controlling excessive shoot growth is one of the most important orchard management practices in deciduous fruit trees (Costa et al., 2002; Forshey and Elfving, 1989; Williams, 1984), and is even more emphasised in the modern era where there is a trend towards high density orchards (Fallahi, 1999). Greene (1999) and Miller and Tworkoski (2003) found that excessive shoot growth had a negative impact on fruit quality (colour, size and packout), yield and pest control. Shading caused by excessive shoot growth also reduced the quality of the return bloom.

Pruning is one of the main horticultural practices used to control shoot growth. However, pruning is time consuming and labour intensive (Byers and Yoder, 1999). Other methods have been used to control shoot growth i.e. ethephon applications, root pruning, dwarfing rootstocks and girdling, but, according to Greene (1999), all of these practices have some negative side effects. Therefore chemicals that control shoot growth are required. Compounds that inhibit gibberellin (GA) biosynthesis have been tested, and although some are successful, e.g. chlormequat and daminozide, their persistence in the tree limits their commercial use (Miller, 2002; Owens and Stover, 1999; Unrath, 1999).

Prohexadione-calcium (P-Ca) is a new plant growth regulator with low toxicity and limited persistence in the tree (Owens and Stover, 1999). P-Ca has been registered as Apogee® in the United States of America and Regalis® in some European countries for the use on apples (Miller and Tworkoski, 2003).

In previous trials with P-Ca, Smit (2002) found that P-Ca reduced shoot growth of apple, pear and plum trees when using physiological active rates of P-Ca, but that a problem with regrowth late in the season occurred and that there was variation in response among pear cultivars occurred.

The purpose of this study was to eliminate the regrowth experienced late in the season, especially in apples, and to investigate the variation in response of pear, plum and nectarine trees at different rates and number of applications of P-Ca. A literature review on fruit development is included to explain the possible relationship between shoot growth and fruit development.

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2. FRUIT DEVELOPMENT IN POME AND STONE FRUIIT

2.1. Introduction

Producing harvestable fruit is a very complex process. Vegetative growth is a strong sink that competes with the fruit on the tree (Byers and Yoder, 1999). According to Quinlan and Preston (1971) the partitioning of dry matter is an important factor in determining the yield. Therefore P-Ca applications that reduce shoot growth can have a major impact on flower and fruit development. This literature review focuses on the different processes that take place as a flower develops into a fruit.

2.2. Morphology of the flower

The flowers of deciduous fruit trees are initiated from shortly after bloom until the middle of summer depending on the cultivar and environmental conditions. Floral initiation is completed by the end of autumn when all of the different flower parts are visible under a microscope, except for the ovules (Dennis, 1986). The apple inflorescence is a cyme with up to eight flowers in apical and axillary buds depending on the cultivar. The flower consists of the receptacle, sepals (collectively called the calyx) and the petals (collectively called the corolla). These are the sterile parts of the flower. The fertile parts of the flower are the stamens, just inside the corolla, and the pistil in the centre of the flower (Fig. 1) (Dennis, 1986).

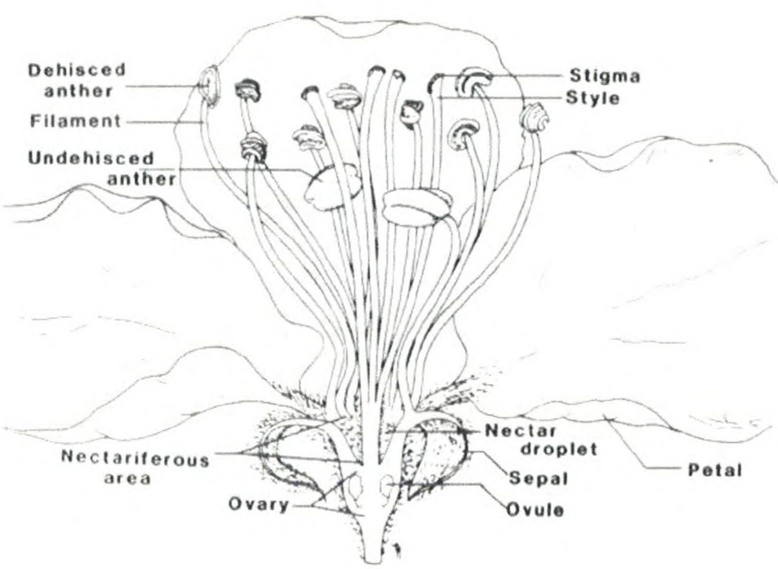

Figure 1. Longitudinal section of 'Delicious' apple flower (Dennis, 1986).

The stamen consists of an anther with four pollen containing chambers and fuse into the filament (Fig. 2). The stamens are collectively called the androecia, which refers to the male gametophytes that form in the anther (Moore et al., 1998). The number of stamens varies, but an apple flower can have up to 20.

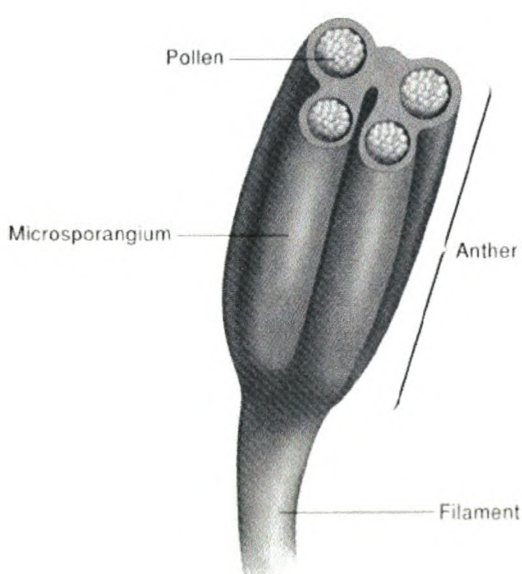

Figure 2. A single stamen, showing pollen in four microsporangia (Moore et al., 1998).

According to Morrison (1964) this was the same for pears, but plums can have up to 30 stamens. Haskell and Dow (1955) also found that plums have between 20 and 30 stamens. Pistils consist of a basal portion called the ovary (enclosed in the receptacle for apples (Dennis, 1986)) and a stigma at the top that is receptive to the pollen. A stalk like style joins these two parts. Inside the ovary are ovule-bearing units called carpels. Apples and pears have five carpels, each with two or four ovules. Peaches and plums originate from a single carpel. Carpels are collectively called the gynoecium, referring to the female gametophytes that are produced in the structure (Dennis, 1986).

2.3. Pollination and fertilisation

Before dehiscence, the pollen grains lose a lot of water (dehydration). In deciduous fruit orchards most of the pollen is transferred from the anther to the stigma by insects. The honey bee (*Apis mellifera* L.) is the most common vector (Williams, 1970). There is some evidence of wind pollination, however the stigma of fruit trees is not adapted to collect windborne pollen and the importance of wind pollination compared to insect pollination is negligible (Williams, 1970).

After adherence of the pollen grain to the stigma, the pollen grain is rehydrated. The effectiveness of pollination depends on the viability of the pollen as well as its compatibility. Pollen from recently dehisced anthers has a high germinating capacity. The compatibility of pollen is determined genetically and there is a lot of variation between cultivars, ranging form self-pollinating to self-sterile (Owens, 1992; Williams, 1970). Visser and Oosthuizen (1982) found that mentor pollen (self-pollen mixed 1:1 with compatible pollen) and pioneer pollen (compatible pollen applied 14 hours before self-pollen) was able to break down barriers, enabling incompatible pollen to complete pollen tube growth in 'Doyenne du Comice' pears. If the pollen is compatible, it germinates on the stigma.

Germination of pollen is temperature dependant and the rate of germination varies between species and cultivars. After germination, the pollen tube grows through the stigma into the style. In some species the stigma is ruptured during development or by insects during pollination and the pollen tubes do not have to penetrate the stigmatic cuticle (Owens, 1992).

Pollen tubes have a marked cytoplasmic polarity and the tube extends by means of tip growth. Growth in the style can be through a stylar canal, intercellularly through transmitting tissue or through an area of cellular debris. Pollen tube growth is heterotrophic and follows the path of least resistance and where enough reserves are available. Starch is digested in reaction to pollination, and only happens in compatible matings of *Petunia* according to Owens (1992).

The rate of pollen tube growth varies among different cultivars and at different temperatures. Growth is triphasic, with initial growth during the penetration of the stigma being very slow. This is followed by a rapid growth period through the style, while growth in the ovary decreases to about the initial growth rate. The movement of the cytoplasmic components in the pollen tube is aided by myosin and actin fibrils at zones of contact (Owens, 1992).

The pollen tube enters the ovary through the obturator, which is a placental protuberance that connects the style with the micropyle. The tube grows in the ovary until it reaches the embryo sac. It penetrates the embryo sac at the base of the egg cell. Two sperm cells are released (Fig. 3); one fertilises the egg and the other fertilises the central or polar nuclei. This is called double fertilisation (Moore et al., 1998; Owens, 1992).

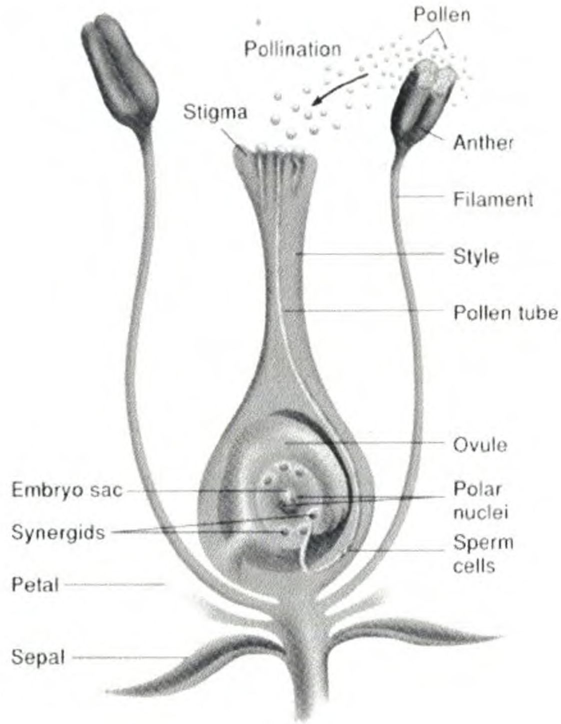

Figure 3. Pollination and fertilisation (Moore et al., 1998).

To achieve fertilisation there is a critical period after flower opening that pollination must take place. This is called the effective pollination period (EPP). The EPP is the time that the embryo sac is viable for fertilisation, minus the time it takes the pollen tube to grow to the embryo sac. This can explain why certain cultivars have a poor fruit set. 'Doyenne du Comice' pear flowers often have an EPP of 1 day and fails to produce good crops, while 'Conference' pear often has an EPP of 10 days and produces heavy crops (Keulemans and Van Laer, 1989; Williams, 1970).

Herrero and Gascon (1987) found that the EPP was prolonged after pollination or treatment with gibberellic acid (GA_3). This was due to the extension of the embryo sac viability of pears. Through this work they indicated that the stimulus induced by pollination might be mediated by GA_3, although the mode of action is not clear. Williams (1970) also showed that the availability of nitrogen and additional late summer nitrogen applications can increase the EPP through increased ovule longevity (Fig. 4), concluding that the EPP limits cropping, rather than a lack of sufficient pollen transfer.

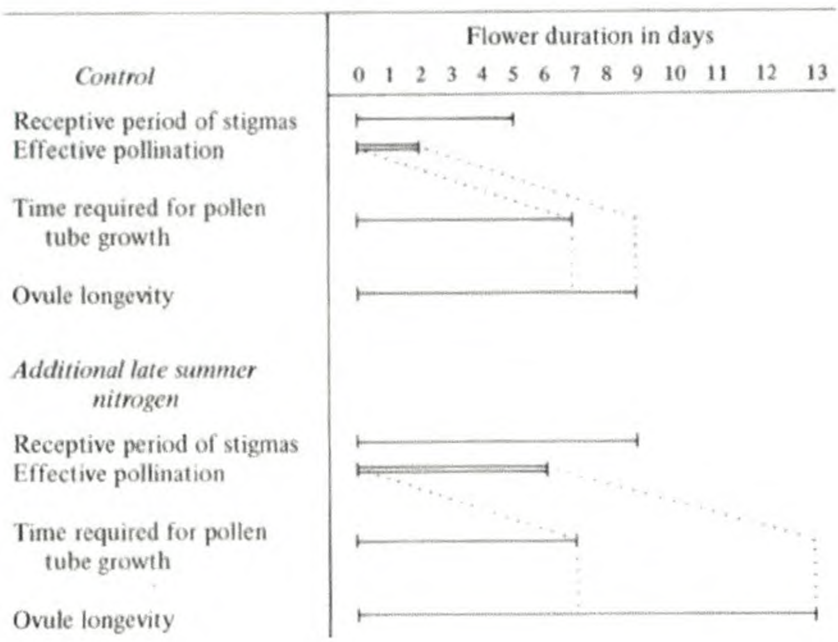

Figure 4. Diagram illustrating the effect of late summer nitrogen on the effective pollination period of apple (Williams, 1970).

2.4. Fruit set

Fruit set is the term used to describe the success of the flower developing into a fruitlet and then into a harvestable fruit. This process involves three steps. Firstly, ovary growth increases after an initial decrease in ovary growth after the flower opens. Abscission at the base of the pedicel must be avoided. This is referred to as the initial set. Secondly, the fruitlet must survive the competition of other fruitlets and vegetative growth. P-Ca can increase fruit set by reducing vegetative growth during this stage. Thirdly, it must survive weather conditions, pests and disease. This is called the final set and the harvested set, respectively (Williams, 1970).

Goldwin (1992) found that the number of fruitlets developing influenced the initial set. The competition between the developing fruit of 'Cox's Orange Pippin' apple caused a decrease in the initial set during certain years. Many of the small fruit abscise during a period of 4 to 6 weeks after full bloom called "June" drop (in the northern hemisphere or "November" drop in the southern hemisphere). He also found that pollinated fruit were able to compete better than parthenocarpic setting fruit. Quinlan and Preston (1971) found that vegetative growth competed with fruit growth in apples and the removal of shoots caused an increase in the initial set. However, this removal of shoots led to an increased "June" drop. They found that tipping the shoots caused an increase in the initial set, as well as an increase in the final set of the apples. This is one of the reasons why prohexadione calcium (P-Ca) can increase fruit set. P-Ca reduces shoot growth, but not the number of leaves, which is important to retain fruit during the "June" drop period (Evans et al., 1999; Quinlan and Preston, 1971).

2.5. Parthenocarpy

According to Schwabe and Mills (1981) parthenocarpy is when fruit develop from flowers that were not fertilised. This is contradictory to the evolutionary advantage of fruit that protects the seeds and assists with the dispersal of seeds. There are very few apple cultivars that are parthenocarpic and of economic importance (Dennis, 2003). However, parthenocarpic fruit set is important in a number of pear cultivars (Schwabe and Mills, 1986). Goldwin (1992) found that applying auxins, gibberellins and cytokinins, either alone or in different combinations, to the developing apple flower or fruitlet, could induce parthenocarpy. Hormone treatments effectively inhibited the abscission of pedicels of unfertilised flowers but their primary mode of action was to re-establish rapid ovary growth. Goldwin (1992) also suggested that the rapid enlargement of the receptacle prevents the degeneration of the nucellus and integuments rather than that growth is dependant on viable ovule tissue.

2.6. Fruit growth

There is a distinct difference in the seasonal growth pattern of pome and stone fruit. These differences will be discussed referring to apple (Fig. 7) and peach fruit growth.

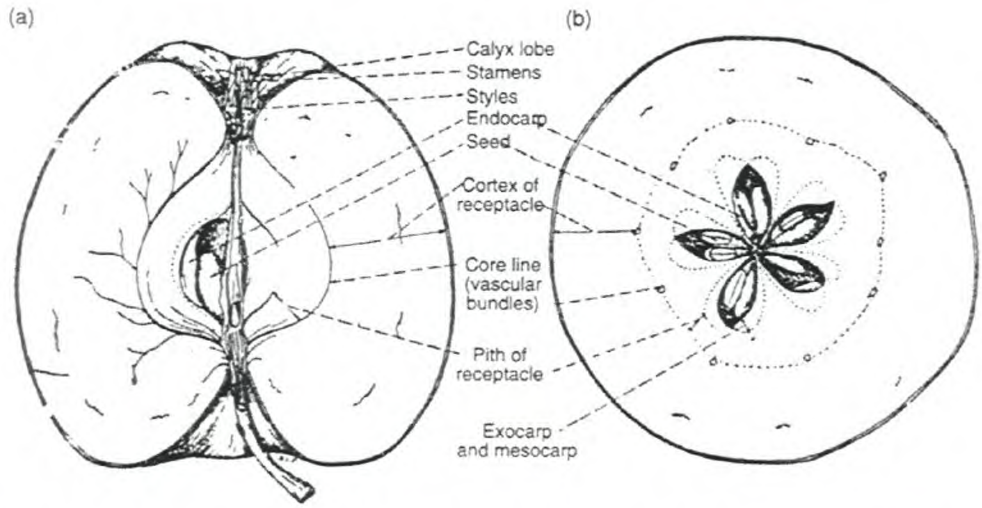

Figure 7. Structure of a mature apple fruit. (a) Vertical section; (b) equatorial section (Dennis , 2003).

Apple fruit grow continuously in diameter until the fruit are harvested. However various parts of the fruit develop at different rates (Fig. 8). This differential within-fruit growth rate results in variation of the ratios, e.g. length to diameter, core to diameter, etc., at different times during fruit development. The first 4 to 6 weeks after full bloom is the stage of rapid cell division in the flesh of the fruit. After this, almost all cell division ceases, but cell enlargement continues until harvest. Fruit growth is much more rapid at night than during the day. The main reason for this is the differences in relative humidity and therefore the increased rates of evapotranspiration during the day. Fruits can contract during the morning, but compensate for loss in size during the day with rapid expansion at night (Dennis, 1986)

Fruit size and shape varies among cultivars and climates, but in most commercial cultivars size and shape are often related to the number and distribution of seeds in an apple fruit. Hormones produced by the seeds may be responsible for these effects (Dennis, 1986; 2003).

In peaches the pericarp follows a double sigmoid growth pattern, with two periods consisting of a rapid increase in size with a period of slow growth in between (Fig. 9).

Therefore the growth curve has been divided into three phases (Basile et al., 2002; Zucconi, 1986).

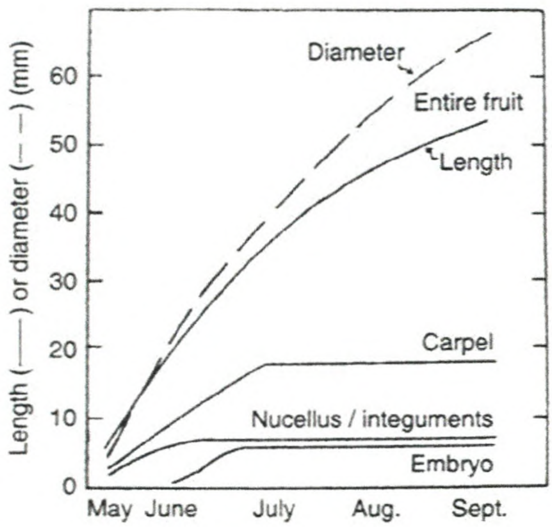

Figure 8. Growth of seed and fruit tissues in a 'McIntosh' apple at Geneva, New York State (Dennis, 2003).

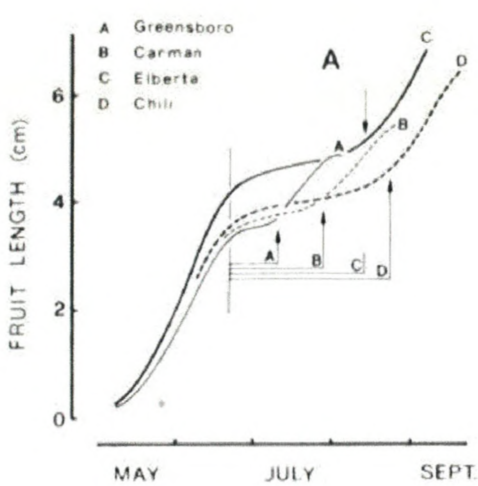

Figure 9. Cumulative growth (polar diameter) of early- and late-maturing peach cultivars (Zucconi, 1986).

Caruso et al. (1997) found that the first and third phases of fruit development are source limited (limited by resources) and the second phase are sink limited (genetic limitations). Basile et al. (2002) found a similar response with plums.

During phase I there is a rapid increase in the volume of the pericarp as well as the seed, with the endocarp reaching 70 to 80% of its mature size by the end of phase I. During this phase the polar and suture diameters are, in succession, the fastest growing giving the fruit an almond-like shape (Fig. 10). Cell division is rapid for the first 2 to 3 weeks, with a rise in cell expansion by the end of the second week. This change in growth rate seems to be correlated with the fertilisation of the ovule. The transition from phase I to phase II seems to be coeval for different peach cultivars under the same conditions, irrespective of the length of the fruit life cycle (Fig. 9) (Zucconi, 1986).

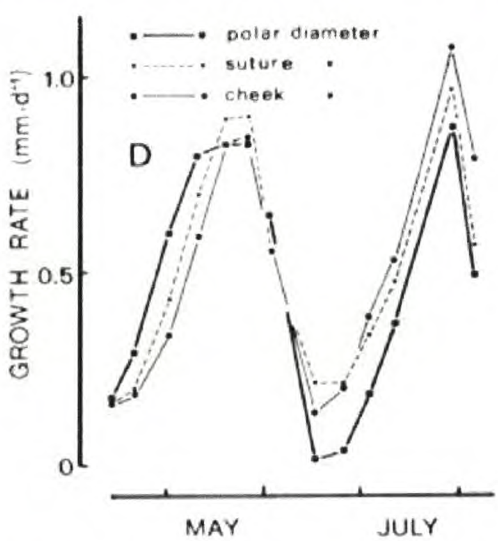

Figure 10. Rate of growth along three fruit diameters for peach fruit (Zucconi, 1986)

During phase II there is a very slow increase in the diameter of the mesocarp, with the most prominent event being the lignification of the endocarp. Lignification begins in the latter stages of phase I with a shift in the dry weight accumulation between the mesocarp and endocarp, which is reversed at the end of phase II. Lignification continues in phase II, but is not very prominent. The duration of this phase can vary from 1 to 9 weeks depending on the cultivar (early or late ripening) and is an important component of the life cycle. If lignification during this stage is not successful, split pit develops which will be discussed below.

Phase III is very important in determining final fruit size and is characterised by a rapid increase in the fresh and dry weight of the mesocarp and rapid cell enlargement in all diameters. During this stage, growth along the cheek diameter is the fastest, giving the fruit its final subglobular shape. The embryo is the last organ that reaches maturity and requires a minimum of 80 days irrespective of the cultivar. That is why some of the early cultivars do not carry viable seeds. The final stages of phase III have a gradual reduction in fruit growth rate coinciding with the transition to fruit maturation. The amount of soluble solids (%) increases again after a reduction during the rapid expansion of the cells (Zucconi, 1986).

2.7. Split pit

Ragland (1934) found that split pit is a physiological disorder of peaches, with a split along the ventral suture of the pit. According to O'Malley and Proctor (2002) and Agenbag et al. (1992) split pit is associated with horticultural practices that are aimed at increasing fruit size, e.g. girdling. Nakano and Nakamura (2002) also found that severe thinning increased the number of fruit with split pit. Early maturing varieties also seem to be more prone to split pit than late-maturing. Split pit is a disorder associated with horticultural practices that alter resource allocation and promote fruit growth (Nakano and Nakamura, 2002). Therefore P-Ca applications can increase the incidence of the disorder.

Ragland (1934) found that lignification did not take place uniformly throughout the pit and that the dorsal suture hardened before the ventral suture. He found that split pit occurred at the end of phase I and beginning of phase II of fruit development, before the ventral suture was completely lignified. During this stage the pit is not able to resist the forces that the growing cells of the flesh exert on it. Nakano and Nakamura (2002) concluded that the pit became brittle, but crisp in early phase II, and that the high tensile strength and plasticity of the flesh caused the cracking of pits in treatments where fruit growth was promoted.

P-Ca is a treatment that should promote fruit growth and it is applied during phase 1 of fruit growth. Therefore, its effect on split pit should be assessed.

2.8. Conclusion

In conclusion, many factors influence the development of a flower to a fruit. All of these factors need to be taken into consideration to produce sustainable yields of good quality fruit.

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PAPER 1: THE EFFECT OF DIFFERENT RATES OF PROHEXADIONE-CALCIUM AND GIRDLING ON SHOOT GROWTH AND FRUIT QUALITY OF FIVE PEAR CULTIVARS

Abstract

Prohexadione-calcium (P-Ca) is a promising new shoot growth retardant that is registered on apples in the United States of America (Apogee®) and some European countries (Regalis®). This gibberellin biosynthesis inhibitor with limited persistence and low toxicity was tested on five pear cultivars. P-Ca reduced shoot growth in all of the cultivars, but there was a marked difference in sensitivity towards different rates of P-Ca among the cultivars. Fruit set was improved in some of the cultivars, which lead to a decrease in final fruit size. P-Ca caused a decrease in return bloom in some of the cultivars. Girdling only reduced shoot growth in one of the cultivars and did not improve fruit set in any of the cultivars. Girdling improved final fruit size and return bloom in almost all of the cultivars. The cultivars are categorised according to their sensitivity towards P-Ca.

Introduction

Controlling excessive vegetative growth is an important horticultural practise in deciduous fruit production (Costa et al., 2002; Forshey and Elfving, 1989; Williams, 1984). Vegetative growth is a strong sink that competes for carbohydrate resources with the fruit on the tree. This competition is at its strongest during the first 50 days after full bloom when shoot growth is rapid (Byers and Yoder, 1999; Elfving et al. 2002). This period is also the important cell division stage of fruit growth. The competition between vegetative and reproductive growth can result in a decreased number of cells in the fruit and, therefore, decrease the capacity of fruit to reach a given size (Cowan et al., 2001; Yamaquchi et al., 2002). Excessive shoot growth also has a negative effect on fruit quality, yield and pest control (Greene, 1999; Miller and Tworkoski, 2003). Shading caused by excessive shoot growth has a negative effect on flower bud induction and the quality of the return bloom (Greene, 1999; Miller and Tworkoski, 2003).

One of the main methods to control shoot growth is pruning. Pruning, however, is a very expensive, labour intensive and time-consuming management practise (Byers and Yoder, 1999). Other control measures have been used, e.g. ethephon applications, pruning, root pruning and dwarfing rootstocks, but these have negative side effects (Greene, 1999). Girdling is also a practice used in pear orchards to control shoot growth, increase fruit set and improve fruit quality (Ingels, 2002; Miller and Tworkoski, 2003; Wilton, 2000). Girdling affects assimilate partitioning and the flow of growth hormones and nutrients throughout the tree (Miller and Tworkoski, 2003).

As gibberellins (GA) have been implicated in stem elongation (Owens and Stover, 1999) researchers have been looking at GA biosynthesis inhibitors to counteract GA and thus reduce shoot growth (Miller, 2002; Unrath, 1999). Although many of these compounds inhibit shoot elongation, e.g. chlormequat and daminozide, their persistence in the tree is a disadvantage (Owens and Stover, 1999).

Prohexadione-calcium [(P-Ca); BAS-125 (3-oxido-4-propionyl-5-oxo-3-cyclohexene-carboxylate)] is a GA biosynthesis inhibitor with low toxicity and limited persistence (Owens and Stover, 1999). The application of P-Ca reduces levels of GA_1 (highly active) and causes the accumulation of its precursor GA_{20} (inactive) (Evans et al., 1999). P-Ca has been registered on apples as Apogee® in the United States of America and as Regalis® in Europe (Miller and Tworkoski, 2003). After mixed results in previous studies on pears (Basak and Rademacher, 2000; Costa et al., 2002; Theron et al., 2002), the response of five different pear cultivars to P-Ca was sudied.

Materials and methods

Plant material

The trials were conducted in the 2002 / 2003 season in commercial pear orchards on La Plaisante Estate in the Wolseley area in the Western Cape, South Africa (33°25'S 19°12'E; ca. 270 m a.s.l.; Mediterranean type climate).

The 'Early Bon Chretien' trees on BP3 rootstock were planted in 1997 at a spacing of 4 x 1.5 m. The orchard was established without cross pollinators. Full bloom was on 11 September 2002. Fruit were hand thinned on 21 October (after a natural fruit drop) according to commercial standards, thinning small fruit to one per cluster, medium fruit to two per cluster and large fruit to three or four per cluster. Fruit were harvested at the commercial harvest date (6 January 2003). Yield in 2000 was 5 $ton.ha^{-1}$, 12 $ton.ha^{-1}$ in 2001, 26 $ton.ha^{-1}$ in 2002 and 41 $ton.ha^{-1}$ in 2003.

The 'Rosemarie' trees on BP3 rootstock were planted in 1994 at a spacing of 4.5 x 1.5 m. The orchard was established without any cross pollinators, but 'Packhams' Triumph' bouquets were brought in during bloom. Full bloom was on 18 September 2002. Fruit were hand thinned on 31 October according to commercial standards. All the very small fruit were removed. Small to medium fruit were thinned to singles and large fruit were thinned to two fruit per cluster to enhance colour development of this blush pear (Theron et al., 2002). Fruit were harvested on 9 January 2003, which was the commercial harvest date. Yield in 2000 was 41 $ton.ha^{-1}$, 28 $ton.ha^{-1}$ in 2001, 40 $ton.ha^{-1}$ in 2002 and 36 $ton.ha^{-1}$ in 2003.

The 'Flamingo' trees on BP3 rootstock were planted in 1997 at a spacing of 4.5 x 1.75 m. Trees were planted without any cross pollinators. Full bloom was on 12 September 2002. The 'Flamingo' trees had a very low fruit set, but hand thinning was done on 21 October according to commercial standards, removing only the very small fruit. Fruit were harvested on 13 January, which was the commercial harvest date. Yield in 2000 was 2 $ton.ha^{-1}$, 5 $ton.ha^{-1}$ in 2001, 12 $ton.ha^{-1}$ in 2002 and 19 $ton.ha^{-1}$ in 2003.

The 'Forelle' trees on BP1 rootstock were planted in 1993 at a spacing of 4.5 x 1.5 m. 'Early Bon Chrectien' was planted as cross pollinator every tenth tree in the row. Full bloom was on 13 September 2002. Progibb® 40% was applied on 10 September at a rate of 2.5 $mg.l^{-1}$ to obtain better fruit set. Fruit were hand thinned on 21 October according to commercial standards. All the clusters were thinned to singles to enhance colour development. Fruit were harvested on 24 February 2003, which was the commercial harvest date. Yield in 2000 was 33 $ton.ha^{-1}$, 18 $ton.ha^{-1}$ in 2001, 25 $ton.ha^{-1}$ in 2002 and 36 $ton.ha^{-1}$ in 2003.

The 'Packham's Triumph' trees on seedling rootstock were planted in 1984 at a spacing of 4.57 x 2 m. 'Clapps Favourite' and 'Winter Nelis' were grafted in the top of every tenth tree as cross pollinators. Full bloom was on 25 September 2002. No hand thinning was done in the orchard. Fruit were harvested on 12 February 2003, which was the commercial harvest date. Yield in 2000 was 82 $ton.ha^{-1}$, 79 $ton.ha^{-1}$ in 2001, 82 $ton.ha^{-1}$ in 2002 and 49 $ton.ha^{-1}$ in 2003.

Treatments and experimental design

There were five treatments (Table 1); three P-Ca treatments, a girdling treatment and an unsprayed control. The wettable granular formulation BAS 125 10W was applied at high volume with a handset mounted on the back of a pick-up truck. This formulation contains 10% (w:w) of P-Ca as active ingredient. The rates and timing of P-Ca treatments were the same for all the cultivars and are summarised in Table 1. In all of the P-Ca treatments the surfactant Dash® was added at a rate of 40 ml.100 l^{-1} water. All of the applications were done in the late afternoon when conditions for absorption were favourable and temperatures were decreasing. The girdling treatment entailed a cut through the bark approximately 30 cm above the ground using the chain of a chain saw. Girdling was performed approximately 2 weeks after full bloom.

A randomised complete block design was used as trial layout with 10 replications and 5 treatments each. A single tree was used per plot.

Data collected

The following data were collected: (1) During bloom two branches per tree were tagged and the number of flower clusters on these branches were counted. The number of fruit set per cluster was determined after the natural fruit drop period. (2) The fruit that were hand thinned from each individual tree were counted and weighed to determine fruit set more accurately. (3) At harvest the fruit of each tree were weighed to determine fruit yield for each treatment. Trunk circumference of each tree was measured. (4) At harvest 25 fruit per tree were randomly sampled and destructively analysed. Fruit length, diameter, fresh weight, firmness, number of developed seeds and the number of seeds with aborted embryos in the fruit were determined. (5) Twenty one-year-old shoots per tree were measured on 19 March 2003 to determine final shoot growth. (6) Return bloom was monitored in 2003. The number of vegetative and reproductive buds on two tagged branches was counted and the reproductive buds expressed as a percentage of the total number of buds. Only the terminal buds were counted on one-year-old shoots.

The General Linear Model (GLM) procedure of the Statistical Analyses System (SAS) was used to analyse the data.

Results

Shoot growth

In 'Rosemarie' all of the P-Ca treatments reduced shoot growth significantly compared to the control and the girdled trees (P=0.0050)(Table 2). Girdling did not reduce shoot growth compared to the control treatment.

This reduction in shoot growth also occurred in the case of 'Early Bon Chretien' (P=0.0030), 'Flamingo' (P=0.0001), 'Packham's Triumph' (P=0.0001) and 'Forelle (P=0.0001)(Table 2). A lack in the response of trees to girdling occurred in all the other cultivars except in 'Forelle'.

For 'Rosemarie' and 'Forelle' there was no significant difference in shoot growth reduction between the different P-Ca treatments. In 'Early Bon Chretien' the 250 $mg.l^{-1}$ treatment had significantly less shoot growth than the other P-Ca treatments. In 'Flamingo' the 2 x 125 $mg.l^{-1}$ treatment had significantly less shoot growth than the 125 $mg.l^{-1}$ treatment. This also occurred in 'Packham's Triumph' where the 250 $mg.l^{-1}$ P-Ca treatment had significantly less shoot growth than the 125 $mg.l^{-1}$ treatment.

Fruit set

P-Ca caused an increase in the fruit set / cluster on the tagged branches for 'Rosemarie' (P=0.0136) (Table 3) and 'Forelle' (P=0.0207) (Table 5). The number and weight of fruit thinned by hand indicated that the P-Ca treatments improved fruit set significantly on 'Rosemarie' (P=0.0004)(P=0.0240)(Table 3) and 'Early Bon Chretien' (P=0.0175)(P=0.0027) (Table 4), but there was no significant improvement in the fruit set of 'Forelle'. There was no significant difference in the fruit set of Flamingo' or 'Packham's Triumph' (data not presented). Girdling did not to improve the fruit set in any of the cultivars.

Fruit size, quality and yield

The mean fruit weight and length of P-Ca treated trees was significantly smaller than fruit from control trees for 'Rosemarie' (P=0.0001)(P=0.0001) (Table 6). There was no significant difference in the mean fruit weight between the control and P-Ca treatments of 'Early Bon Chretien' (Table 7) and 'Flamingo' (Table 8). 'Early Bon Chretien' had fruit with a significantly smaller fruit length and diameter on the P-Ca treated trees (P=0.0099)(P=0.0110). The P-Ca treated trees of 'Flamingo' had fruit with a significantly smaller fruit length (P= 0.0001). There was no significant difference in fruit size of 'Packham's Triumph' (Table 9) and 'Forelle' (Table 10) among the treatments.

Girdling improved fruit weight, length and diameter of 'Flamingo' compared to the control and P-Ca treated trees. Girdling also improved fruit length of 'Early Bon Chretien' compared to the control and P-Ca treated trees. Girdling had no significant effect on fruit size of 'Rosemarie', 'Packham's Triumph' or 'Forelle'.

There was no significant difference in fruit firmness, number of developed seeds and seeds with aborted embryos per fruit or the yield (kg harvested / cm trunk circumference) among any of the treatments for any of the cultivars (data not presented). There was no significant difference in yield (kg harvested / cm trunk circumference) between the different treatments (data not presented).

Return bloom

For all of the cultivars, the return bloom was significantly higher in the girdled treatment than the other treatments (Table 11), except for 'Packham's Triumph' where return bloom was not significantly different from the control. No significant difference was found in return bloom between the control and P-Ca treatments for 'Early Bon Chretien', 'Flamingo' and 'Rosemarie'. For 'Early Bon Chretien' the 250 $mg.l^{-1}$ P-Ca treatment had a significantly smaller percentage of reproductive buds than the 125 $mg.l^{-1}$ and 2 x 125 $mg.l^{-1}$ P-Ca treatments. The P-Ca treatments on 'Forelle' and 'Packham's Triumph' significantly reduced the number of reproductive buds (P=0.0201)(P=0.0004), however there was no significant difference between the different P-Ca treatments.

Discussion

P-Ca significantly reduced shoot growth in all of the pear cultivars studied. According to the data, pear cultivars can be separated into three groups according to their sensitivity to different rates of P-Ca. The first category responded well at low rates (125 $mg.l^{-1}$) of P-Ca. 'Rosemarie' is an example of such a cultivar where an increase in P-Ca concentration did not have better shoot growth control. Theron et al. (2002) had similar results with 'Rosemarie'.

The second category consisted of cultivars that responded well to higher rates of P-Ca (250 $mg.l^{-1}$), e.g. 'Flamingo', 'Early Bon Chretien' and 'Packham's Triumph'. Costa et al. (2001) found that four P-Ca applications at 100 $mg.l^{-1}$ significantly reduced shoot growth but four applications at 50 $mg.l^{-1}$ did not significantly reduce shoot growth of 'Abbe Fetel' pears. Applying this higher rate of P-Ca as a split application i.e. 2 x 125 $mg.l^{-1}$ rather than a single 250 $mg.l^{-1}$ treatment is advisable. The 250 $mg.l^{-1}$ treatment caused more regrowth later in the season after harvest (data not presented), especially in 'Early Bon Chretien'. This second growth flush is hard to explain (Elfving et al., 2003) and an effective control strategy is still unclear. Elfving et al. (2002) found four different shoot growth patterns in different pear cultivars. Three of these patterns consisted of more than one growth flush. Multiple applications (even 3 or more) may be needed

(Elfving et al., 2003) to control this second growth flush. The relationship between the rate of the initial application and the second growth flush should be investigated.

The third category consisted of cultivars that did not respond even at high rates of P-Ca. 'Forelle' falls into this category. Although some shoot growth control was obtained, the total amount of shoot growth was still much more than in any of the other cultivars and shoot growth control was insufficient (Figure 1).

In previous work, Smit (2002) had similar results with different rates of P-Ca and the response of different cultivars. From her work it seems that 'Golden Russet Bosc' pear also falls into the second category. Basak and Rademacher (2000) also found that 'Conference' only had shoot growth control at the highest concentration (225 $mg.l^{-1}$) of P-Ca that was applied.

P-Ca had a negative influence on fruit size in 'Rosemarie' and 'Early Bon Chretien', possibly as an effect of the higher fruit set in these cultivars. 'Forelle' was the most difficult cultivar in which to control shoot growth and P-Ca did not cause an increase in the fruit set (according to the number and weight of fruit thinned by hand) or a decrease in fruit size. In 'Packham's Triumph' there was no increase in fruit set and no decrease in fruit size. The decrease in fruit size seems to be related to an increase in fruit set of the P-Ca treatments. Sugar et al. (2002) had similar results where P-Ca treatments resulted in smaller fruit size of 'Barlett' pears and suggested that it was due to an increased fruit set. Costa et al. (2001) found that P-Ca applications increased fruit size in 'Abbe Fetel' pears. Greene (1999) found that P-Ca increased fruit set in apples. Higher fruit set causes more competition in the critical cell division stage. Instead of reducing competition by reducing shoot growth, competition is increased because of more fruit on the tree. The increased fruit set is an indication that more assimilates are available for fruit growth when shoot growth is reduced in the cell division stage. This can be managed better with earlier hand thinning or even a chemical thinner. The interaction between reduced shoot growth by P-Ca treatment and earlier fruit thinning should be investigated, however, because of the natural fruit drop period that still has to follow, this approach might cause over thinning of fruit.

Sugar et al. (2002) also found that P-Ca treatments lead to a considerable decline in return bloom in 'Beurré Bosc', 'Anjou', 'Red Anjou' and 'Bartlett' pears. They also found a difference in sensitivity to the reduction in return bloom with 'Beurré Bosc' being the most sensitive and 'Bartlett' the least sensitive. The reduction in return bloom did not significantly affect cropping. In the current study we found a similar difference in sensitivity in return bloom among cultivars to the rate and timing of P-Ca applications. Further trials with rates and timing on different cultivars is needed to determine which P-Ca applications provide good shoot growth control without any adverse effects.

Girdling did not increase fruit set in any of the pear cultivars studied. Girdling only significantly reduced shoot growth in 'Forelle'. Theron et al. (2002) also found that girdling was not effective in controlling shoot growth on 'Rosemarie'. In all of the cultivars studied the girdled trees had the largest fruit. This phenomenon is hard to explain and must be investigated in more detail. Girdling increased return bloom in all of the cultivars except for 'Packham's Triumph'.

The combination of girdling and P-Ca treatments should be investigated. If these two practices can compliment one another, the combination could be a useful horticultural practise to control vegetative growth, increase fruit size and improve return bloom.

In conclusion it can be said that P-Ca was effective in increasing fruit set and controlling shoot growth in most of the pear cultivars in this study, but P-Ca had a negative effect on fruit size. Girdling did not increase fruit set or reduce shoot growth but did increase fruit size and return bloom in most of the pear cultivar studied. More research is needed to optimise fruit production using these two vegetative growth control techniques and to determine how different pear cultivars react to these treatments.

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Tables

Table 1. Summary of prohexadione-calcium treatments applied to 'Early Bon Chretien', 'Rosemarie', 'Flamingo', 'Forelle' and 'Packham's Triumph' pear trees.

P-Ca concentration	Time of application (Total amount applied)
Control	-
Girdled	2 weeks after full bloom[1]
125 $mg.l^{-1}$	5 – 10 cm shoot growth[2]
2 × 125 $mg.l^{-1}$	5 – 10 cm shoot growth[2] + 4 weeks later[3]
250 $mg.l^{-1}$	5 – 10 cm shoot growth[2]

[1]At petal drop in the case of 'Packham's Triumph'

[2]At petal drop in the case of 'Rosemarie'

[3]3 weeks later in the case of 'Packham's Triumph'

Table 2. The effect of girdling and prohexadione-calcium (P-Ca) applied at different rates on the shoot growth of 'Early Bon Chretien', 'Rosemarie', 'Flamingo', 'Packham's Triumph' and 'Forelle' pears at La Plaisante Estate, Wolsely.

	Shoot growth (cm)				
Treatments	Rosemarie	Early BC	Flamingo	Packham's Triumph	Forelle
Control	25.71 a	31.47 ab	55.78 a	34.82 a	61.65 a
Girdled	25.95 a	35.04 a	54.67 a	33.90 a	58.44 b
1×125 $mg.l^{-1}$ P-Ca	20.94 b	28.97 b	40.24 b	24.20 b	57.23 bc
2×125 $mg.l^{-1}$ P-Ca	21.37 b	28.04 b	31.73 c	21.72 bc	53.53 c
1×250 $mg.l^{-1}$ P-Ca	21.33 b	21.82 c	36.10 bc	18.86 c	56.57 bc
Significance level					
Trt	0.0050	0.0001	0.0001	0.0001	0.0014
Control vs. P-Ca	0.0025	0.0030	0.0001	0.0001	0.0001

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 3. The effect of girdling and prohexadione-calcium (P-Ca) applied at different rates on fruit set of 'Rosemarie' pears at La Plaisante Estate, Wolsely.

Treatments	Fruit set / cluster	Fruit thinned by hand per tree (kg)	Fruit thinned by hand per tree (no)
Control	0.67 b	0.53 bc	66.7 cd
Girdled	0.76 b	0.44 c	55.8 d
1×125 mg.l^{-1} P-Ca	1.00 ab	0.75 ab	129.7 ab
2×125 mg.l^{-1} P-Ca	0.96 ab	0.65 bc	108.9 bc
1×250 mg.l^{-1} P-Ca	1.16 a	0.92 a	161.4 a
Significance level			
Trt	0.0584	0.0049	0.0001
Control vs. P-Ca	0.0136	0.0240	0.0004

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 4. The effect of girdling and prohexadione-calcium (P-Ca) applied at different rates on fruit set of 'Early Bon Chretien' pears at La Plaisante Estate, Wolsely.

Treatments	Fruit set / cluster	Fruit thinned by hand per tree (kg)	Fruit thinned by hand per tree (no)
Control	1.07 a	0.44 bc	68.5 c
Girdled	0.95 a	0.04 c	58.5 c
1×125 mg.l^{-1} P-Ca	1.50 a	0.47 bc	78.4 bc
2×125 mg.l^{-1} P-Ca	1.15 a	0.59 b	105.0 ab
1×250 mg.l^{-1} P-Ca	1.16 a	0.86 a	121.5 a
Significance level			
Trt	0.4789	0.0001	0.0021
Control vs. P-Ca	0.4585	0.0027	0.0175

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 5. The effect of girdling and prohexadione-calcium (P-Ca) applied at different rates on fruit set of 'Forelle' pears at La Plaisante Estate, Wolsely.

Treatments	Fruit set / cluster	Fruit thinned by hand per tree (kg)	Fruit thinned by hand per tree (no)
Control	1.60 a	1.52 a	311.7 a
Girdled	1.98 a	1.66 a	324.9 a
1×125 $mg.l^{-1}$ P-Ca	2.46 a	1.95 a	374.8 a
2×125 $mg.l^{-1}$ P-Ca	1.99 a	1.59 a	364.7 a
1×250 $mg.l^{-1}$ P-Ca	2.00 a	1.61 a	375.3 a
Significance level			
Trt	0.0667	0.5159	0.4276
Control vs. P-Ca	0.0207	0.3581	0.0932

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 6. The effect of girdling and prohexadione-calcium (P-Ca) applied at different rates on fruit length, fruit diameter and fruit weight of 'Rosemarie' pears at La Plaisante Estate, Wolsely.

Treatments	Length (mm)	Diameter (mm)	Weight (g)
Control	83.9 a	59.7 ab	132.6 a
Girdled	82.5 a	61.3 a	137.1 a
1×125 $mg.l^{-1}$ P-Ca	71.4 b	58.6 bc	115.5 b
2×125 $mg.l^{-1}$ P-Ca	69.9 bc	58.7 bc	112.3 b
1×250 $mg.l^{-1}$ P-Ca	67.8 c	57.4 c	107.2 b
Significance level			
Trt	0.0001	0.0021	0.0001
Control vs. P-Ca	0.0001	0.0560	0.0001

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 7. The effect of girdling and prohexadione-calcium (P-Ca) applied at different rates on fruit length, fruit diameter and fruit weight of 'Early Bon Chretien' pears at La Plaisante Estate, Wolsely.

Treatments	Length (mm)	Diameter (mm)	Weight (g)
Control	83.7 b	68.9 ab	187.6 a
Girdled	86.00 a	69.7 a	204.9 a
1×125 mg.l^{-1} P-Ca	81.4 dc	68.1 bc	194.00 a
2×125 mg.l^{-1} P-Ca	82.7 bc	66.4 d	179.4 a
1×250 mg.l^{-1} P-Ca	79.9 d	66.8 dc	185.2 a
Significance level			
Trt	0.0001	0.0012	0.1102
Control vs. P-Ca	0.0099	0.0110	0.8502

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 8. The effect of girdling and prohexadione-calcium (P-Ca) applied at different rates on fruit length, fruit diameter and fruit weight of 'Flamingo' pears at La Plaisante Estate, Wolsely.

Treatments	Length (mm)	Diameter (mm)	Weight (g)
Control	81.6 b	64.1 b	158.0 b
Girdled	84.6 a	67.1 a	182.1 a
1×125 mg.l^{-1} P-Ca	76.4 c	64.4 b	154.5 b
2×125 mg.l^{-1} P-Ca	75.7 c	63.1 b	148.8 b
1×250 mg.l^{-1} P-Ca	76.7 c	63.9 b	152.1 b
Significance level			
Trt	0.0001	0.0003	0.0001
Control vs. P-Ca	0.0001	0.6432	0.1167

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 9. The effect of girdling and prohexadione-calcium applied at different rates on fruit length, fruit diameter and fruit weight of 'Packham's Triumph' pears at La Plaisante Estate, Wolsely.

Treatments	Length (mm)	Diameter (mm)	Weight (g)
Control	83.8 ab	75.1 ab	236.3 ab
Girdled	85.8 a	76.9 a	254.4 a
1×125 $mg.l^{-1}$ P-Ca	82.9 abc	74.8 ab	234.4 ab
2×125 $mg.l^{-1}$ P-Ca	81.00 bc	74.2 b	227.9 bc
1×250 $mg.l^{-1}$ P-Ca	80.6 c	72.9 b	210.8 c
Significance level			
Trt	0.0057	0.0332	0.0109
Control vs. P-Ca	0.0566	0.2602	0.2064

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 10. The effect of girdling and prohexadione-calcium (P-Ca) applied at different rates on fruit length, fruit diameter and fruit weight of 'Forelle' pears at La Plaisante Estate, Wolsely.

Treatments	Length (mm)	Diameter (mm)	Weight (g)
Control	80.3 ab	66.2 a	174.8a
Girdled	81.7 a	68.4 a	193.9 a
1×125 $mg.l^{-1}$ P-Ca	78.00 bc	67.5 a	180.9 a
2×125 $mg.l^{-1}$ P-Ca	79.00 bc	66.7 a	175.1 a
1×250 $mg.l^{-1}$ P-Ca	77.6 c	67.2 a	175.3 a
Significance level			
Trt	0.0213	0.2361	0.0694
Control vs. P-Ca	0.0581	0.2664	0.7046

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 11. The effect of girdling and prohexadione-calcium (P-Ca) applied at different rates on the return bloom [(reproductive buds / (reproductive buds + vegetative buds) ×100)] of 'Early Bon Chretien', 'Rosemarie', 'Flamingo', 'Packham's Triumph' and 'Forelle' pears at La Plaisante Estate, Wolsely.

	Reproductive buds (%)				
Treatments	Rosemarie	Early BC	Flamingo	Packham's Triumph	Forelle
Control	46.9 b	29.7 bc	35.6 b	29.9 ab	15.3 b
Girdled	57.2 a	44.9 a	53.1 a	30.9 a	32.3 a
1×125 $mg.l^{-1}$ P-Ca	46.3 b	30.7 b	36.3 b	23.2 bc	8.2 bc
2×125 $mg.l^{-1}$ P-Ca	48.0 b	32.1 b	42.8 b	13.1 c	6.5 c
1×250 $mg.l^{-1}$ P-Ca	48.5 b	24.9 c	34.8 b	20.8c	9.6 bc
Significance level					
Trt	0.0114	0.0001	0.0033	0.0001	0.0001
Control vs. P-Ca	0.7874	0.8378	0.5448	0.0004	0.0201

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Figures

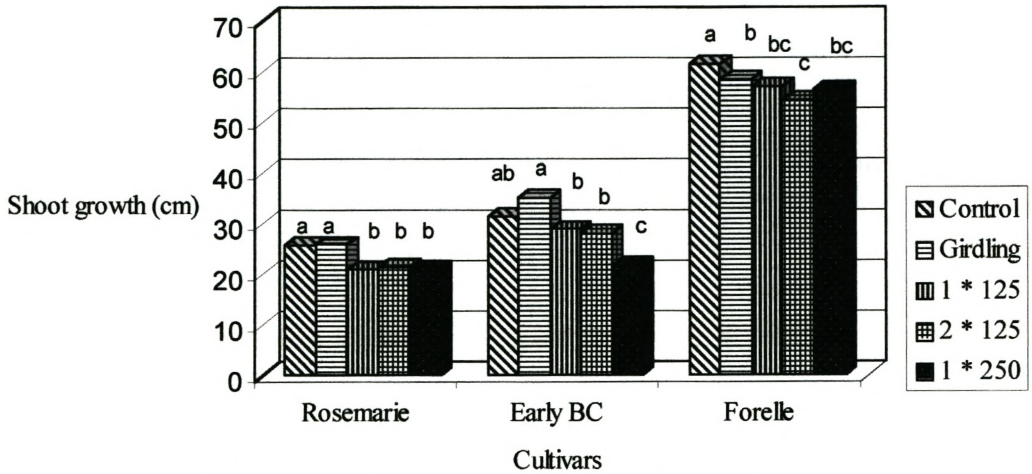

Fig. 1. The effect of different rates of P- Ca on the final shoot length of three pear cultivars

PAPER 2: AN ADVANCED EVALUATION OF PROHEXADIONE-CALCIUM ON APPLE TREES

Abstract

Controlling vigorous shoot growth in apple orchards is essential. Prohexadione-calcium (P-Ca) is a promising new shoot growth retardant that is registered on apples in the United States of America (Apogee®) and some European countries (Regalis®). P-Ca has shown good shoot growth control in previous studies in South Africa, but there was a problem with regrowth late in the season. In two trials during the 2001 / 2002 season, multiple applications of P-Ca were able to significantly reduce shoot growth in 'Golden Delicious' and 'Granny Smith' apples. This caused an increase in fruit size of 'Golden Delicious'. There was no carry-over effect of P-Ca on the growth of trees that were previously treated and left unsprayed in this trial, however there was an improvement in fruit size of 'Golden Delicious'. Very little regrowth occurred late in the season. During 2002 / 2003, a single application of P-Ca was unable to reduce shoot growth of 'Golden Delicious' and 'Granny Smith'. Adding a surfactant (Dash®) did not enhance the effect of P-Ca in any of the trials, but applications were made when conditions for absorption were already favourable. P-Ca was able to reduce shoot growth and improve fruit size and flower bud development, especially in 'Golden Delicious'.

Introduction

In deciduous fruit orchards there is a need to balance the relationship between vegetative growth and cropping (Miller and Tworkoski, 2003). Excessive shoot growth reduces flowering and cropping (Forshey and Elfving, 1989) whereas moderate shoot growth with good light penetration in the canopy is important for sustained yields of high quality fruit (Basak and Rademacher, 2000). Good light penetration is also important for flower bud formation (Cain, 1971) and red colour development in fruit (Greene, 1999). The competition between fruit and shoot growth is at its highest during the first 50 days after full bloom when 70 – 80 % of the season's shoot growth is completed (Byers and Yoder, 1999; Elfving et al., 2002). This competition during the cell division stage can decrease the number of cells in the fruit and therefore the fruit's capacity to reach a certain size (Cowan et al., 2001; Yamaquchi et al., 2002). Controlling excessive shoot growth is very important (Costa et al., 2002; Forshey and Elfving, 1989; Williams, 1984), especially the first growth flush that often contribute 70 to 80 % of the seasonal growth (Miller and Tworkoski, 2003). Currently, various horticultural practices are used to control vegetative growth, including dwarfing rootstocks, pruning, limited fertilising and deficit irrigation. However, these techniques are not always as effective as chemical growth inhibitors (Elfving and Procter, 1986).

Prohexadione-calcium [(P-Ca); BAS-125 (3-oxido-4-propionyl-5-oxo-3-cyclohexene-carboxylate)] is a gibberellin biosynthesis inhibitor with low toxicity and limited persistence (Owens and Stover, 1999). It is absorbed foliarly, transported acropetaly within the tree (Evans et al., 1999) and is effective for 3 to 4 weeks (Unrath, 1999). P-Ca is registered on apples in the United States of America (Apogee®) and some European countries (Regalis®) (Miller and Tworkoski, 2003). From previous work (Basak and Rademacher, 2000; Byers and Yoder, 1999; Evans et al., 1997; Greene, 1999; Miller, 2002; Unrath, 1999) it is clear that P-Ca is able to reduce shoot growth in apples. Smit (2002) had good results on 'Golden Delicious' and 'Granny Smith' apples, but experienced regrowth late in the season. She ascribed this to poor absorption of later applications, when temperatures were high and humidity low.

The aim of this study was to reduce vegetative regrowth with multiple applications of P-Ca and by adding surfactants (Dash® and Wenkem® oil) to the P-Ca treatments. The repeated use of P-Ca and the carry-over effect from previously sprayed trees was also investigated.

Materials and methods

Plant material

Two trials were conducted during the 2001 / 2002 season and one trial was conducted during the 2002 / 2003 season. 'Golden Delicious' and 'Granny Smith' apple trees from same orchard on the farm High Noon in the Villiersdorp area of the Western Cape, South Africa (33° 59'S, 19°17'E; ca.365m a.s.l.; Mediterranean climate) were used.

Carry-over effect trial (Trial 1): The trial was conducted during the 2001 / 2002 season on 'Golden Delicious' and 'Granny Smith' apple trees to evaluate the carry-over effect of P-Ca. The 'Golden Delicious' trees were used in P-Ca trials during the 1999 / 2000 and 2000 / 2001 seasons (Smit, 2002; Table 1). The orchard was established in 1987 on M793 rootstock at a spacing of 4.57 x 2.74 m. Trees were planted with 'Granny Smith' as cross pollinator. Full bloom was on 9 October 2001. Chemical thinning was done on 14 October applying 125 ml Promalin® and 70 g Golden Thin® per100 l water. Fruit were harvested on 11 April 2002, which was the commercial harvest date. The yield in 1998 was 54 $t.ha^{-1}$, 53 $t.ha^{-1}$ in 1999, 53 $t.ha^{-1}$ in 2000, 52 $t.ha^{-1}$ in 2001 and 75 $t.ha^{-1}$ in 2002.

'Granny Smith' apple trees that served as the cross pollinator 'Golden Delicious' were used in P-Ca trials in the 2000 / 2001 season (Table 1). Full bloom was on 8 October 2001. No chemical thinning was done and fruit were hand thinned after the natural fruit drop period. Commercial harvesting started on 11 April 2002. Yield in 1998 was 41 $t.ha^{-1}$, 35 $t.ha^{-1}$ in 1999, 57 $t.ha^{-1}$ in 2000, 54 $t.ha^{-1}$ in 2001 and 52 $t.ha^{-1}$ in 2002.

Surfactant trial 1 (Dash®) (Trial 2): This trial was conducted during the 2001 / 2002 season in the same orchard as trial 1. P-Ca was not previously applied to these trees.

Surfactant trial 2 (Dash® vs. Wenkem® oil) (Trial 3): This trial was conducted during the 2002 / 2003 season, using the same trees as in trial 1. For 'Golden Delicious' full bloom was on 9 October 2002. Chemical thinning was done on 14 October applying 125 ml Promalin® and 70 g Golden Thin® per 100 l water. Yield in 2003 was 72 $t.ha^{-1}$. For 'Granny Smith' full bloom was on 8 October 2002. No chemical thinning was done and fruit were hand thinned after the natural fruit drop period. The yield in 2003 was 65 $t.ha^{-1}$.

Treatments and experimental design

The wettable granular formulation BAS 125 10W was applied at high volume with a handset mounted on the back of a pick-up truck. This formulation contains 10 % (w:w) of P-Ca as active ingredient. The timing and rate of application was the same for the

'Golden Delicious' and 'Granny Smith' trees. The rate and timing of P-Ca applications are summarised in Table 2, 3 and 4. In trial 1 and 2 the surfactant Dash® was added at a rate of 60 ml.100 l^{-1} and in trial 3 at a rate of 40 ml.100 l^{-1}. All of the applications were done in the late afternoon when temperatures were decreasing and conditions for absorption were favourable.

The trial layout was a randomised complete block design with 10 single-tree replicates of four treatments in trial 1 and 3. There were nine treatments in trial 2.

Data collected

Trial 1 and 2: (1) Two representative branches were tagged on each tree and the number of flower clusters on each branch were counted. After the natural fruit drop period the number of fruit on each branch was counted to determine the fruit set. (2) Ten one-year-old shoots were tagged per tree (5 - 15 cm) and measured at 4-week intervals until the cessation of shoot growth. (3) At harvest 25 fruit per tree were randomly sampled and destructively analysed. Their diameter, length and weight were measured. The amount of stem and calyx-end russet was determined by using the A43 and A40 DFB (Deciduous Fruit Board) charts for 'Golden Delicious' and 'Granny Smith' apples, respectively. Calyx-end russet rated on a scale of 1 o 12 with 1 being the minimum and 12 the maximum russet development. Fruit colour of 'Golden Delicious' was evaluated on a scale of 1 to 9 using the DFB chart A28 (1 = green; 9 = yellow). 'Granny Smith' fruit colour was rated on a scale of 1 to 12 according to the DFB chart A38 (1 = green; 12 = yellow). The number of developed seeds and seeds with aborted embryos were also counted. (4) The fruit of each tree were individually weighed and trunk circumference measured to determine the yield of every treatment ($kg.cm^{-1}$ trunk circumference).

Trial 3: (1) At harvest 25 fruit per tree were randomly sampled and destructively analysed. Their diameter, length, weight and the number of developed seeds and seeds with aborted embryos were determined, (2) the fruit of each tree were individually weighed and the trunk circumference measured to determine the yield of each treatment. Unfortunately, due to a misunderstanding, the fruit of the 'Golden Delicious' trees were harvested before data could be recorded and (3) at the cessation of growth, 20 one-year-old shoots per tree were measured to determine the final shoot length for each treatment.

Shoot measurements were converted to percentages using the formula: $((X - Y)/Y) \times 100$, where X = shoot length at the measurement date and Y = initial shoot length. The General Linear Model (GLM) procedure of the Statistical Analysis System (SAS) was used to analyse the data.

Results

Shoot growth

Trial 1: P-Ca caused a significant reduction in shoot growth of 'Golden Delicious' in the 4 x 67 $mg.l^{-1}$ P-Ca treatment without Dash® (Table 5; Figure 1). The treatment with Dash only reduced shoot growth compared to the previously sprayed treatment. There was no significant difference between the treatments with and without the surfactant. Both of the P-Ca treatments caused a significant reduction in shoot growth of 'Granny Smith' trees (Table 5; Figure 2). There was no significant difference between the P-Ca treatments with and without the surfactant added.

Trial 2: All of the P-Ca treatments were able to reduce the shoot growth of the 'Golden Delicious' apple trees (Table 6; Figure 3). There was no significant difference between the different P-Ca treatments. In 'Granny Smith', shoot growth was only reduced where P-Ca was applied three or four times (Table 6; Figure 4). There was no significant difference between the P-Ca treatments where the surfactant was added and the treatments without the surfactant.

Trial 3: P-Ca treatments did not reduce final shoot length of 'Golden Delicious' or 'Granny Smith' apple trees (Table 7). There was no significant difference between the different P-Ca treatments.

Fruit size, quality and yield

Trial 1: P-Ca treatments significantly increased the fruit size of 'Golden Delicious' according to the mean fruit length, diameter, and weight compared to the first control treatment (Table 8). The previously sprayed treatment (left unsprayed to determine a possible carry over effect) also improved fruit length, diameter and weight compared to the control treatment. There was no significant difference in fruit size between the P-Ca treatments or between the P-Ca treatments and the previously sprayed treatment. In Trial 2 the P-Ca treatments had no effect on fruit length, but as in Trial 1 all of the P-Ca treatments increased fruit diameter and fruit weight, except for the 1 x 67 $mg.l^{-1}$ P-Ca without Dash®, that did not improve fruit diameter significantly (Table 9).

In 'Granny Smith' there was no significant difference in fruit length, diameter or weight between the treatments in any of the three trials (Table 10).

P-Ca had no significant effect on the number of developed seeds or seeds with aborted embryos of 'Golden Delicious' and 'Granny Smith' in any of the trials (data not presented). None of the treatments had an effect on the ground colour or the severity of russet on the fruit. There was no significant effect on the yield of 'Golden Delicious' or 'Granny Smith' in any of the trials (data not presented).

Fruit set and return bloom

P-Ca did not significantly affect return bloom of 'Golden Delicious' or 'Granny Smith' trees in trial 1 and 2. P-Ca did not significant effect on fruit set of 'Golden Delicious' or 'Granny Smith' trees in any of the trials (data not presented).

Discussion

All of the P-Ca was able to reduce shoot growth in 'Golden Delicious' during the 2001 / 2002 season. The single application of 67 $mg.l^{-1}$ was not able to reduce shoot growth in 'Golden Delicious' during the 2002 / 2003 season (Table 7). It seems that an early application (petal drop), even at a low rate of 67 $mg.l^{-1}$, followed by applications throughout the season, was able to reduce shoot growth. Miller (2002) also found that the timing of the initial application is more important than the rate. This is due to the fact that 70 % to 80% of the season's growth occurs within 32 days of petal drop (Byers and Yoder, 1999; Unrath, 1999). In the 2002 / 2003 season P-Ca was applied at 5 to 15 cm shoot growth, which might have been too late. If P-Ca is applied after the effective period a single application cannot provide season-long shoot growth control (Greene, 1999; Miller 2002; Unrath, 1999). P-Ca was also able to reduce shoot growth in 'Granny Smith' trees in the 2001 / 2002 season. 'Granny Smith' seemed to be less sensitive to P-Ca, and a minimum of three applications (effective cumulative dose of 201 $mg.l^{-1}$) was needed to obtain season-long control. In the 2002 / 2003 season P-Ca did not reduce shoot growth in 'Granny Smith' apple trees. This also seemed to be due to the application at 5 – 15 cm (rather than petal fall) and a too low cumulative dose.

There was no carry-over effect of P-Ca on shoot growth of 'Golden Delicious' or 'Granny Smith' trees and no significant difference between the previously sprayed treatments and the unsprayed treatments. The 'Golden Delicious' trees in trial 1 had a significant improvement in fruit size of previously sprayed trees. This carry-over effect could be due to improved flower bud development because of the reduced vigour in the previous year (Cain, 1971; Greene, 1999).

P-Ca improved fruit size of 'Golden Delicious' in the 2001 / 2002 season. Basak and Rademacher (2000) had similar increases in fruit size of 'Lobo' apple. P-Ca did not improve fruit size of 'Granny Smith' in either of the seasons. Due to the reduction in shoot growth in the 2001 / 2002 season, an increase (as in 'Golden Delicious') was expected. The lack of fruit size response may be due to secondary thickening of the tips of one-year-old shoots. Smit (2002) had similar results with 'Granny Smith', and this in increase of fruit size has also been found in other apple cultivars (Basak and Rademacher, 2000; Byers and Yoder, 1999; Miller, 2002). P-Ca did not have a significant effect on the number of the developed seeds, number of seeds with aborted embryos, ground colour or the severity of russet on 'Golden Delicious' or 'Granny Smith' in either of the seasons. There was no significant effect on fruit set of 'Golden Delicious' or 'Granny Smith' apples. Greene (1999), Unrath (1999) and Basak and Rademacher (2000) reported an increase in fruit set of certain apple cultivars following P-Ca application.

The addition of surfactant did not enhance the effect of P-Ca. The surfactants were added to improve the absorption of P-Ca. All of the P-Ca was applied in the late afternoon when temperatures were decreasing and humidity was higher. These conditions were already for absorption. If applications are made during the day when temperatures are high and humidity is low, these surfactants could increase the effectiveness of the P-Ca applications.

In conclusion, multiple applications of P-Ca (and early single applications on 'Golden Delicious') reduced shoot growth in 'Golden Delicious' and 'Granny Smith' apples and prevented vegetative regrowth. P-Ca was most effective with multiple applications, provided that the first application was very early. A later, single application was not able to control shoot growth throughout the season. The addition of a surfactant appears to be unnecessary if P-Ca is applied under conditions conducive to optimal foliar absorption.

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Tables

Table 1. Concentration and timing of prohexadione-calcium applications on 'Golden Delicious' and 'Granny Smith' trees on High Noon farm, Villiersdorp (Smit, 2002).

Treatments	Time of application
1999 / 2000: 'Golden Delicious'	
Control (unsprayed)	-
3×50 $mg.l^{-1}$	Petal drop (PD) + 2 weeks after PD + 4 weeks after PD
4×50 $mg.l^{-1}$	PD + 2 weeks after PD + 4 weeks after PD + 6 weeks after PD
3×67 $mg.l^{-1}$	PD + 2 weeks after PD + 4 weeks after PD
2000 / 2001: 'Golden Delicious' and'Granny Smith'	
Control (unsprayed)	-
3×50 $mg.l^{-1}$	Full bloom (FB)/PD +5 weeks after FB/PD + 45 days before harvest
4×50 $mg.l^{-1}$	FB/PD +5 weeks after FB/PD + between 2nd and last spray + 45 days before harvest
3 ×67 $mg.l^{-1}$	FB/PD +5 weeks after FB/PD + 45 days before harvest

Table 2. Concentration and timing of prohexadione-calcium applications on 'Golden Delicious' and 'Granny Smith' apple trees on High Noon farm, Villiersdorp (Trial 1).

Treatments	Time of application
Control (unsprayed)	-
Previously sprayed (unsprayed)	-
3×67 $mg.l^{-1}$	PD + 4 weeks after PD + 6 weeks before harvest
3×67 $mg.l^{-1}$ + Dash®	PD + 4 weeks after PD + 6 weeks before harvest

Table 3. Concentration and timing of prohexadione-calcium applications on 'Golden Delicious' and 'Granny Smith' trees on High Noon farm, Villiersdorp (Trial 2).

Treatments	Time of application
Control (unsprayed)	-
1×67 $mg.l^{-1}$	PD
1×67 $mg.l^{-1}$ + Dash®	PD
2×67 $mg.l^{-1}$	PD + 4 weeks after PD
2×67 $mg.l^{-1}$ + Dash®	PD + 4 weeks after PD
3×67 $mg.l^{-1}$	PD + 4 weeks after PD + 6 weeks before harvest
3×67 $mg.l^{-1}$ + Dash®	PD + 4 weeks after PD + 6 weeks before harvest
4×67 $mg.l^{-1}$	PD + 4 weeks after PD + 6 weeks before harvest + after harvest
4×67 $mg.l^{-1}$ + Dash®	PD + 4 weeks after PD + 6 weeks before harvest + after harvest

Table 4. Concentration and timing of prohexadione-calcium applications on 'Golden Delicious' and 'Granny Smith' apple trees on High Noon farm, Villiersdorp (Trial 3).

Treatments	Time of application
Control (unsprayed)	-
1×67 $mg.l^{-1}$ + Wenkem® oil (1%)	5 – 15 cm shoot growth
1×67 $mg.l^{-1}$	5 – 15 cm shoot growth
1×67 $mg.l^{-1}$ + Dash®	5 – 15 cm shoot growth

Table 5. The effect of prohexadione-calcium applied at different rates on the shoot growth of 'Golden Delicious' and 'Granny Smith' apple trees on High Noon farm, Villiersdorp (Trial 1).

	Shoot growth (%)	
Treatments	'Golden Delicious'	'Granny Smith'
Control	37.4 ab	192.4 a
Previously sprayed (unsprayed)	49.6 a	163. a
3×67 mg.l^{-1}	11.7 c	96.4 b
3×67 mg.l^{-1} + Dash®	19.4 bc	84.9 b
Significance level	*0.0031*	*0.0001*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 6. The effect of prohexadione-calcium applied at different rates on the shoot growth of 'Golden Delicious' and 'Granny Smith' apple trees on High Noon farm, Villiersdorp (Trial 2).

	Shoot growth (%)	
Treatments	'Golden Delicious'	'Granny Smith'
Control	48.6 a	162.3 a
1×67 mg.l^{-1}	21.0 b	143.0 ab
1×67 mg.l^{-1} + Dash®	16.4 b	142.1 ab
2×67 mg.l^{-1}	20.5 b	96.0 abc
2×67 mg.l^{-1} + Dash®	21.0 b	110.3 abc
3×67 mg.l^{-1}	17.3 b	76.4 bc
3×67 mg.l^{-1}+ Dash®	15.1 b	51.2 c
4×67 mg.l^{-1}	17.4 b	76.7 bc
4×67 mg.l^{-1} + Dash®	17.3 b	88.9 bc
Significance level	*0.0001*	*0.0380*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 7. The effect of prohexadione-calcium applied at different rates on the shoot growth of 'Golden Delicious' and 'Granny Smith' apple trees on High Noon farm, Villiersdorp (Trial 3).

	Shoot growth (%)	
Treatments	'Golden Delicious'	'Granny Smith'
Control	22.0 a	29.2 a
1×67 $mg.l^{-1}$ + Wenkem® oil (1%)	21.6 a	28.1 a
1×67 $mg.l^{-1}$	22.6 a	27.9 a
1×67 $mg.l^{-1}$ + Dash®	24.4 a	30.4 a
Significance level	*0.1060*	*0.3709*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 8. The effect of prohexadione-calcium applied at different rates on fruit length, fruit diameter and fruit weight of 'Golden delicious' apple trees on High Noon farm, Villiersdorp (Trial 1).

Treatments	Length (cm)	Diameter (cm)	Weight (g)
Control	62.9 b	67.0 b	139.4 b
Previously sprayed (unsprayed)	65.9 a	71.0 a	160.2 a
3×67 $mg.l^{-1}$	66.5 a	71.8 a	171.2 a
3×67 $mg.l^{-1}$ + Dash®	65.6 a	70.7 a	164.3 a
Significance level	*0.0031*	*0.0001*	*0.0001*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 9. The effect of Prohexadione-calcium applied at different rates on fruit length, fruit diameter and fruit weight of 'Golden Delicious' apple trees on High Noon farm, Villiersdorp(Trial 2).

Treatments	Length (cm)	Diameter (cm)	Weight (g)
Control	64.1 a	67.5 b	148.5 b
1×67 mg.l^{-1}	68.5 a	69.1 ab	173.5 a
1×67 mg.l^{-1} + Dash®	67.3 a	70.9 a	167.7 a
2×67 mg.l^{-1}	67.6 a	71.2 a	170.8 a
2×67 mg.l^{-1} + Dash®	66.4 a	70.7 a	168.8 a
3×67 mg.l^{-1}	67.1 a	70.1 a	165.2 a
3×67 mg.l^{-1} + Dash®	66.8 a	70.8 a	169.6 a
4×67 mg.l^{-1}	68.1 a	71.0 a	173.4 a
4×67 mg.l^{-1} + Dash®	66.1 a	70.6 a	167.0 a
Significance level	*0.5063*	*0.0484*	*0.0005*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 10. The effect of Prohexadione-calcium applied at different rates on fruit length, fruit diameter and fruit weight of 'Granny Smith' apples on High Noon farm, Villiersdorp (Trial 3).

Treatment	Length (cm)	Diameter (cm)	Weight (g)
Control	66.2 a	72.2 a	167.3 a
1×67 mg.l^{-1}+Wenkem® 1%	66.3 a	71.6 a	168.8 a
1×67 mg.l^{-1}	67.4 a	72.3 a	172.5 a
1×67 mg.l^{-1} + Dash®	66.6 a	71.7 a	168.8 a
Significance level	*0.4174*	*0.7003*	*0.6743*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Figures

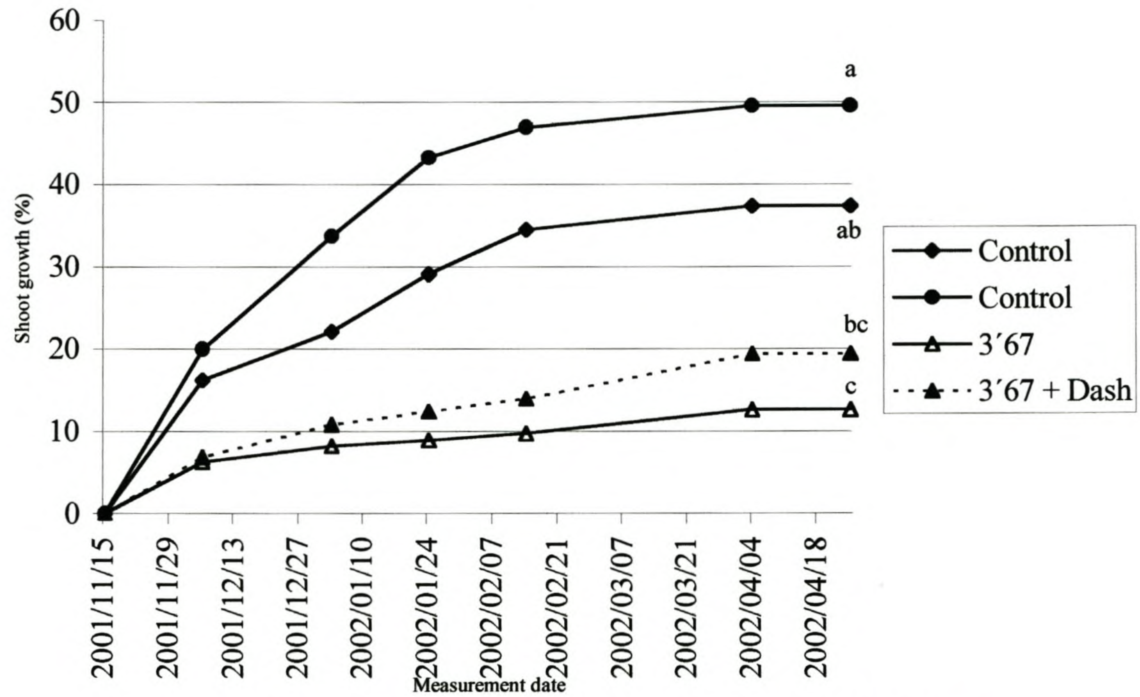

Figure 1. The effect of P-Ca on shoot growth of 'Golden Delicious' apple trees on High Noon farm, Villiersdorp (Trial 1).

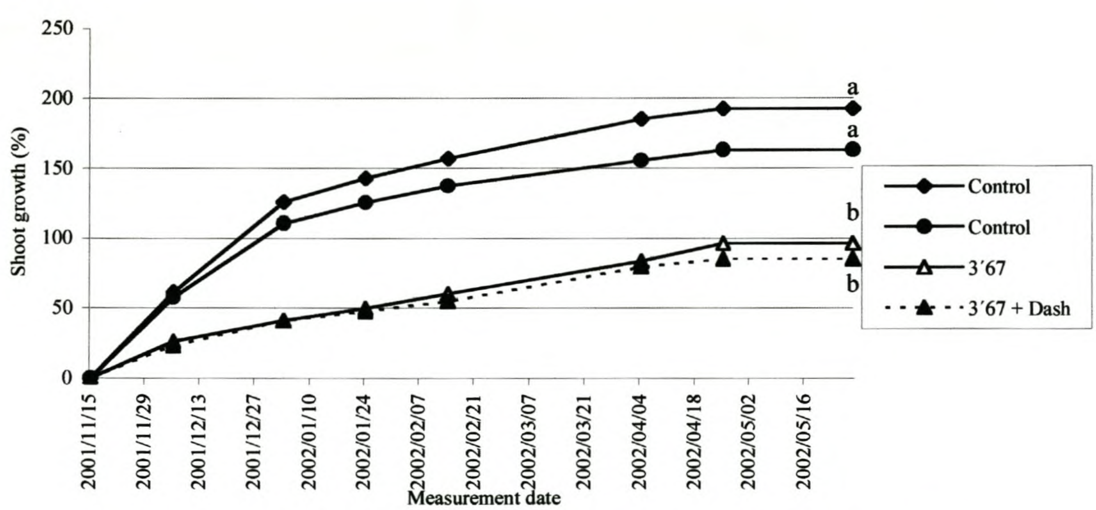

Figure 2. The effect of P-Ca on shoot growth of 'Granny Smith' apple trees on High Noon farm, Villiersdorp (Trial 1).

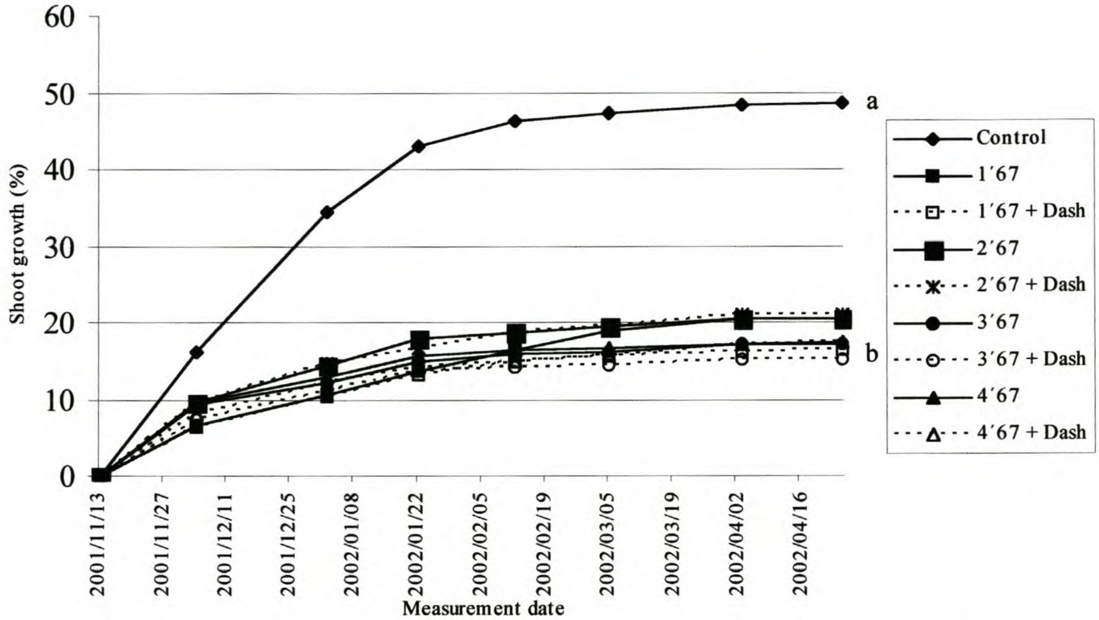

Figure 3. The effect of P-Ca on shoot growth of 'Golden Delicious' apple trees on High Noon farm, Villiersdorp (Trial 2).

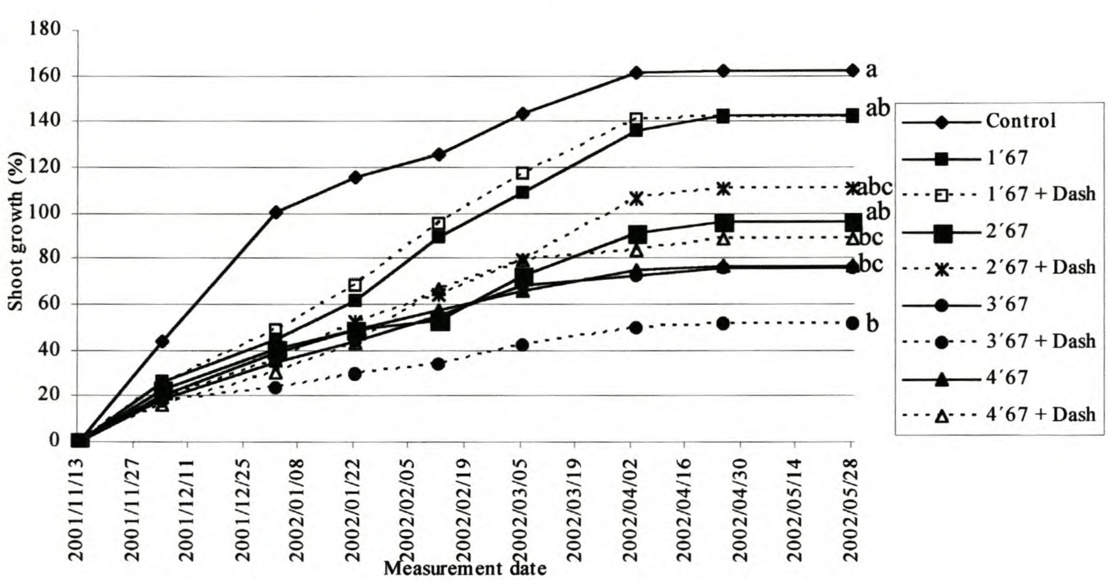

Figure 4. The effect of P-Ca on shoot growth of 'Granny Smith' apple trees on High Noon farm, Villiersdorp (Trial 2).

PAPER 3: THE EFFECT OF PROHEXADIONE-CALCIUM ON SHOOT AND FRUIT GROWTH OF PLUMS AND NECTARINES

Abstract

Prohexadione-calcium (P-Ca) is a promising new plant growth retardant that is used to control shoot growth on apple trees in the United States of America and some countries in Europe. This gibberellin biosynthesis inhibitor is effective in controlling shoot growth, but is not as persistent in the tree as products that are currently used. Trials were conducted on 'Pioneer' and 'Songold' plum trees which have a natural inclination for vigorous shoot growth, and an early nectarine, 'May Glo'. Different rates of P-Ca were applied at 5 to 10 cm shoot growth to reduce competition between fruit and shoot growth. P-Ca reduced shoot growth on plum trees but not on nectarine trees. P-Ca did not have a significant effect on fruit size, yield or internal fruit quality. More trials need to be conducted to determine the proper rates of P-Ca for different stone fruit cultivars.

Introduction

Controlling vegetative growth in deciduous fruit orchards is important in the production of high quality fruit (Basak and Rademacher, 2000; Costa et al., 2002; Forshey and Elfving, 1989; Williams, 1984). This is even more important in plums, which are naturally inclined to vigorous growth (Basak and Jakóbczak, 1998) and have a limited number of dwarfing rootstocks or compact scions to choose from for growth control (Miller and Tworkoski, 2003; Rademacher, 1995) available to control vigorous growth.

Currently the gibberellin (GA) biosynthesis inhibitor paclobutrazol is used to control shoot growth in some fruit tree species (Basak and Jakóbczak, 1998; Greene, 1999). Due to its long persistency in the tree (Owens and Stover, 1999) the widespread use of paclobutrazol is not possible (Basak and Jakóbczak, 1998).

Prohexadione-calcium (P-Ca) is a GA biosynthesis inhibitor that is currently registered on apples as Apogee® in the United States of America and as Regalis® in some European countries (Miller and Tworkoski, 2003). Its limited persistence in the tree and low toxicity are advantages (Owens and Stover, 1999).

P-Ca inhibits GA biosynthesis in the latter stages and reduces the active GA_1 to its inactive precursor GA_{20}, resulting in shortened internodes and a reduction in shoot length (Evans et al., 1999; Rademacher, 1993; 1995). P-Ca is absorbed foliarly and can be applied as soon as an appropriate leaf area is available (5 to 10 cm shoot growth). Reduction of shoot growth is apparent 2 weeks after application (Greene, 1999).

During the first 50 days after full bloom, shoot growth is very rapid in plum trees (Bostan, 1998). According to Basile et al. (2002) this is a source-limited stage in stone fruit development and fruit and shoot growth are in competition with one another. The early suppression of shoot growth should reduce competition with fruit growth during this source-limited stage.

The concomitant development of floral and vegetative buds, which are in the same axil in peaches and nectarines, has a significant influence in the set and persistence of the flower in these fruit trees due to these competing sinks (Erez et al., 2000). This is aggravated in warmer climates where rest-breaking agents are applied that promote the earlier break of vegetative buds (Erez et al., 2000).

Although little research has been conducted with P-Ca on stone fruit species, its ability to reduce early shoot growth in other fruit trees is encouraging (Smit, 2002).

The objective of this study was to determine whether P-Ca could suppress early shoot growth in plum and nectarine trees and its effect on fruit growth and final fruit size.

Material and methods

Plant material

The trials were conducted during the 2002 / 2003 season in commercial plum orchards on Môrelig farm in the Wemmershoek area of the Western Cape, South Africa. The cultivars Pioneer and Songold were used. The 'May Glo' nectarine orchard on the farm Timberlea in the Stellenbosch area of the Western Cape was used.

'Pioneer' is an early plum cultivar. Full bloom was on 16 August 2002 and commercial harvesting started on 14 November 2002 and continued until 22 November 2002. 'Pioneer' develops a pinkish red colour and therefore cannot be strip picked. The orchard, on 'Marianna' rootstock, was established in 1997 at a spacing of 4 x 1.5 m without any cross-pollinators. Fruit were hand thinned to one plum every 10 cm shoot length. Yield in 2000 was 4 $t.ha^{-1}$, 15 $t.ha^{-1}$ in 2001, 23 $t.ha^{-1}$ in 2002 and 20 $t.ha^{-1}$ in 2003.

'Songold' is a yellow plum cultivar and the orchard was established in 1993 on 'Marianna' rootstock at a spacing of 4 x 1.5 m. 'Laetitia' is used as cross pollinator with the 'Songold' and 'Laetitia' rows alternating. Full bloom was on 2 September 2002. Fruit were hand thinned to 1 plum every four-finger widths. The fruit were harvested on 30 January 2003, which was the commercial harvest date. Yield in 2000 was 9.3 $t.ha^{-1}$, 6.8 $t.ha^{-1}$ in 2001, 42 $t.ha^{-1}$ in 2002 and 35 $t.ha^{-1}$ in 2003.

'May Glo' is an early maturing, small-fruited nectarine cultivar with a yellow background colour that develops a red blush. Full bloom was on 30 June 2002 and commercial harvesting started on 25 October 2002 and continued until 8 November 2002. The orchard was established in 1992 on peach rootstock at a spacing of 4 x 1.2 m. Hand thinning was done at full bloom and flowers were thinned to about one flower every 15 cm shoot length. Yield in 2000 was 12 $t.ha^{-1}$, 16 $t.ha^{-1}$ in 2001, 17 $t.ha^{-1}$ in 2002 and 20 $t.ha^{-1}$ in 2003.

Treatments and experimental design

The experimental design was the same for all three cultivars.The wettable granular formulation BAS 125 10W was applied at high volume with a handset mounted on the back of a pick-up truck. This formulation contains 10% (w:w) of P-Ca as active ingredient. The rates and timing of P-Ca applications are summarised in Table 1. The surfactant Dash® was added to all of the P-Ca treatments at a rate of 40ml.100 l^{-1} water to all of the P-Ca treatments applied to the plum trees, and at 60ml.100 l^{-1} water on the nectarine trees. All of the applications were done in the late afternoon when conditions for absorption were favourable and temperatures were decreasing. One treatment was left as an unsprayed control.

A randomised complete block design was used as trial layout with 10 replications and 4 treatments each (Table 1). A single tree was used per plot for the plums. Two trees were used per plot for the nectarines.

Data collected

The following data were collected: (1) After the P-Ca treatment was applied, 10 shoots per plot were tagged and subsequently measured at two-week intervals until the cessation of shoot growth. (2) Ten fruit per plot were tagged and their diameter measured at two-week intervals until harvest for 'Songold' and 'May Glo'. The 'Pioneer' fruit diameter was measured at weekly intervals until harvest. (3) At harvest the fruit of each tree were individually weighed to determine the yield for each treatment. (4) At harvest, 25 fruit per plot were randomly sampled, and diameter, weight and firmness were measured. A refractometer (Atago N1; 0 – 32% Brix) was used to determine Brix. The number of plum fruit with the distal part of the endocarp broken off was counted. The number of nectarine fruit with split pit were counted.

Shoot and fruit measurements were converted to percentages using the formula: $((X - Y)/Y) \times 100$, where X = shoot length / fruit diameter at the measurement date and Y = initial shoot length / fruit diameter. The General Linear Model (GLM) procedure of the Statistical Analysis System (SAS) was used to analyse the data.

Results

Shoot growth

Unfortunately, due to a misunderstanding, the 'Pioneer' trees were pinched when shoot growth started after full bloom and 10 days later. Therefor the P-Ca was applied much later (16 October 2002) than planned when shoot growth started again. P-Ca was applied when extension shoot growth was 5 to 10 cm. Shoot growth of the 125 $mg.l^{-1}$ and 250 $mg.l^{-1}$ P-Ca treatments was significantly less than that of the control 14 days after P-Ca application (Figure 1). There was no significant difference in final shoot length between the control and the 62.5 $mg.l^{-1}$ P-Ca treatment. There was no significant difference in final shoot length between the 125 $mg.l^{-1}$ and 250 $mg.l^{-1}$ P-Ca treatments.

Initially, all of the P-Ca treatments reduced shoot growth in 'Songold' compared to the control treatment (Figure 2). However, shoot growth of the P-Ca treatments caught up with control treatments through the course of the season, and at the end of the season there was no significant difference in the percentage shoot growth among the control, 62.5 $mg.l^{-1}$ and 125 $mg.l^{-1}$ P-Ca treatments. The 250 $mg.l^{-1}$ P-Ca-treatment had significantly more shoot growth than the other treatments. In mid-November, more vigorous shoots were broken out to improve light penetration in the canopy of the 'Songold' trees. Unfortunately some of the tagged shoots were also broken out. More of the tagged shoots were removed on the control treatment because these trees were more vigorous than the trees treated with P-Ca. This contributed to the apparent decline in shoot growth rate (Figure 2) of the control treatment, and the P-Ca treated trees catching up towards the end of December.

Initially, the 125 $mg.l^{-1}$ and 250 $mg.l^{-1}$ P-Ca-treatments tended to reduce shoot growth (20% less shoot growth) on 'May Glo' nectarine (Figure 3). However, this reduction in shoot growth was not statistically significant. These treatments caught up with the control and 62.5 $mg.l^{-1}$ P-Ca treatment during November. At the cessation of shoot growth there were no differences among the control and P-Ca treated trees.

Fruit size, quality and yield

There was no significant difference in fruit weight, diameter or yield of 'Pioneer' (Table 2), 'Songold' (Table 3) or 'May Glo' (Table 4) among any of the treatments. P-Ca treatments did not affect the incidence of fruit with the distal part of the endocarp broken off, fruit firmness or Brix in any of the cultivars. In 'May Glo' the 125 $mg.l^{-1}$ and 250 $mg.l^{-1}$ P-Ca treatments significantly reduced the incidence of fruit with split pit (data not presented), however the percentage of fruit with split pit was very low. No significant difference among treatments was found in the fruit growth curves (from the 10 tagged fruit) of 'Pioneer' (Figure 4), 'Songold' (Figure 5) or 'May Glo' (Figure 6) throughout the course of the season.

Discussion

The 125 $mg.l^{-1}$ and 250 $mg.l^{-1}$ P-Ca treatments significantly reduced shoot growth in 'Pioneer' plum. Unfortunately the P-Ca was applied 2 months after full bloom. In trials on rootstock vigour, Caruso et al. (1997) showed that reduced vegetative growth altered dry mass partitioning in favour of fruit growth in 'Flordaprince' peach trees. Even though there was no significant difference in fruit size of 'Pioneer' in this study, an earlier application of P-Ca might have had a more pronounced effect. Earlier control of vigorous shoot growth should reduce competition in stage I (cell division) of fruit growth which is source-limited (Basile et al., 2002; Caruso et al., 1997). Such a response should have an effect on fruit size.

Basak and Rademacher (2000) found that P-Ca treatments were effective in controlling shoot growth on 'Stanley' plum and 'Dabrowice' and 'Lowicz' prunes. They also found that there was a marked difference in sensitivity to P-Ca between these cultivars. All of the cultivars responded to the 225 $mg.l^{-1}$ P-Ca treatment, but shoot growth control was only obtained in 'Lowicka' prune at 125 $mg.l^{-1}$ P-Ca treatment. This also occurred in 'Pioneer' where the 125 $mg.l^{-1}$ and 250 $mg.l^{-1}$ P-Ca treatments reduced shoot growth significantly, but the 62.5 $mg.l^{-1}$ P-Ca treatment did not to reduce shoot growth.

In 'Songold plum, all of the P-Ca treatments initially reduced shoot. During the course of the season shoot growth of the P-Ca treated trees caught up with that of the control treatment. P-Ca is only effective for 4 to 6 weeks in fruit trees and has limited persistence. A second application of P-Ca could control shoot growth throughout the course of the season. Smit (2002) also found that P-Ca was effective in controlling shoot growth in 'Songold' and a second application reduced the regrowth later in the season. According to Zucconi (1986), stage III is the stage of fruit growth with the biggest increase in fruit size of peaches. Reducing competition in this stage could increase fruit size.

Although there was no difference in fruit growth rate (FGR) of the treatments in stage I (source-limited) or stage II (sink-limited) of fruit development, all of the P-Ca-treatments tended to a higher FGR in stage III (source-limited). The tagged fruit on P-Ca-treated trees were marginally larger at harvest, although this difference was not significant. This is hard to explain, but may indicate that more cells were synthesized during cell division in these fruit. Smit (2002) also found that although shoot growth was reduced significantly, there was no significant difference in fruit size and yield between treated and untreated trees.

The P-Ca treatments did not reduce the initial shoot growth of 'May Glo' nectarine significantly. Byers and Yoder (1999) found that a P-Ca treatment of 375 $mg.l^{-1}$ did not able to reduce shoot growth in 'Redhaven' peaches. Basak and Rademacher (2000) found that concentrations of 250 $mg.l^{-1}$ P-Ca reduced shoot growth in the same cultivar. According to Caruso et al. (1997), fruit growth occurs concurrently with the major vegetative growth flush in the spring. This concurrent growth can reduce final fruit size due to limited resource availability, especially in early ripening peach cultivars. The 125 $mg.l^{-1}$ and 250 $mg.l^{-1}$ P-Ca treatments slightly reduced shoot growth, which probably caught up with the other treatments due to the limited persistence of P-Ca. However, this increase in shoot growth rate only happened after harvest and helps to ensure good bearing wood for the following season. The decrease in shoot growth did not cause an increase in the fruit size of 'May Glo'.

P-Ca reduced shoot growth on plums but not on nectarine trees. P-Ca did not improve fruit size of plums or nectarines. This research encourages more trials on stone fruit.

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Tables

Table 1. Summary of single prohexadione-calcium treatments applied to 'Pioneer' and 'Songold' plums and 'May Glo' nectarine.

P-Ca concentration	Time of application
Control	-
62.5 mg.l^{-1}	5 – 10 cm shoot growth[1]
125 mg.l^{-1}	5 – 10 cm shoot growth[1]
250 mg.l^{-1}	5 – 10 cm shoot growth[1]

[1]Applied 2 months after full bloom in the case of 'Pioneer' when shoot growth started after pinching.

Table 2. The effect of prohexadione-calcium (P-Ca) applied at different rates on fruit weight, fruit diameter and yield of 'Pioneer' plum at Môrelig farm, Wemmershoek.

Treatments	Weight (g)	Diameter (mm)	Yield (kg/tree)
Control	61.62 a	48.98 a	18.92 a
62.5 mg.l^{-1} P-Ca	61.53 a	48.35 a	17.54 a
125 mg.l^{-1} P-Ca	58.29 a	48.08 a	20.55 a
250 mg.l^{-1} P-Ca	61.67 a	48.41 a	18.18 a
Significance level	*0.1466*	*0.6943*	*0.4691*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 3. The effect of prohexadione-calcium applied at different rates on fruit weight, fruit diameter and yield of 'Songold' plum at Môrelig farm, Wemmershoek.

Treatments	Weight (g)	Diameter (mm)	Yield (kg/tree)
Control	92.91 a	53.32 a	42.51 a
62.5 $mg.l^{-1}$ P-Ca	90.89 a	52.82 a	50.84 a
125 $mg.l^{-1}$ P-Ca	91.42 a	53.18 a	43.47 a
250 $mg.l^{-1}$ P-Ca	87.66 a	52.68 a	38.06 a
Significance level	*0.2625*	*0.6268*	*0.1360*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 4. The effect of prohexadione-calcium applied at different rates on fruit weight, fruit diameter and yield of 'May Glo' nectarine at Timberlea farm, Stellenbosch.

Treatments	Weight (g)	Diameter (mm)	Yield (kg/plot)
Control	92.97 a	52.85 a	51.93 a
62.5 $mg.l^{-1}$ P-Ca	96.11 a	53.51 a	22.82 a
125 $mg.l^{-1}$ P-Ca	95.73 a	51.74 a	22.28 a
250 $mg.l^{-1}$ P-Ca	95.77 a	53.91 a	22.10 a
Significance level	*0.8193*	*0.1654*	*0.9495*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Figures

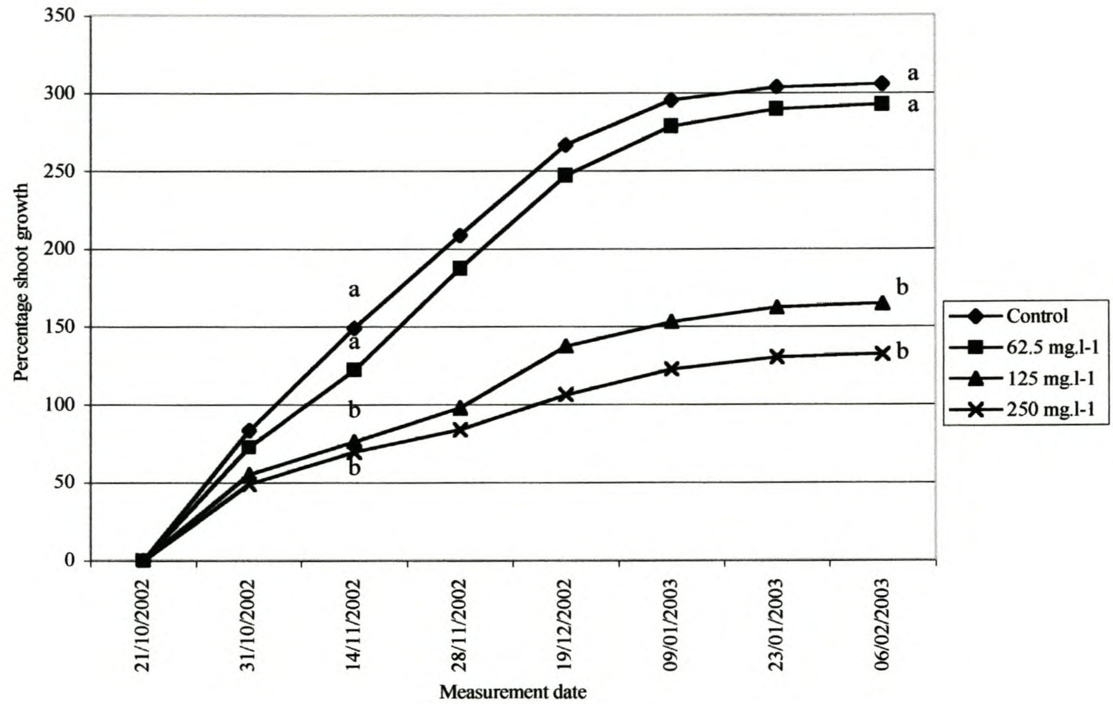

Figure 1. The effect of P-Ca applied at different rates on the shoot growth of 'Pioneer' plums at Môrelig farm, Wemmershoek.

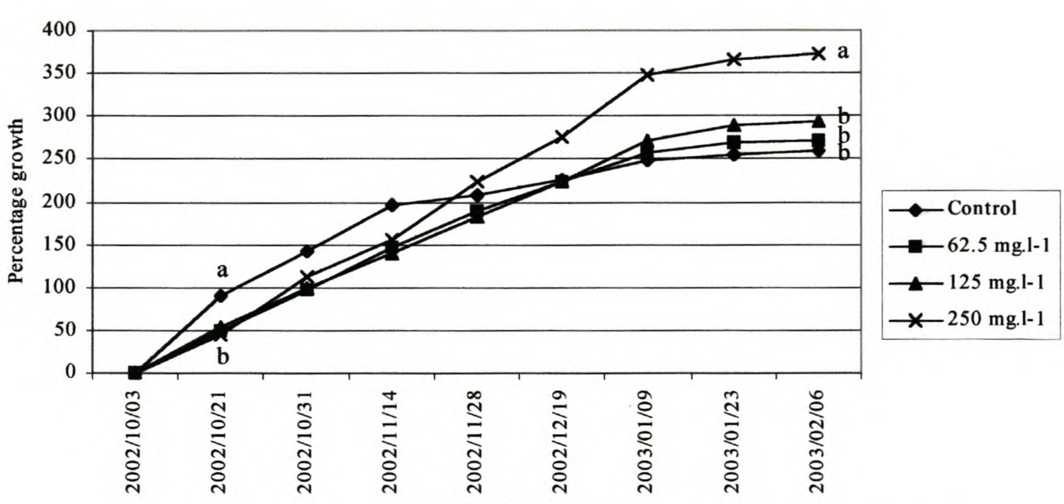

Figure 2. The effect of P-Ca applied at different rates on the shoot growth of 'Songold' plum at Môrelig farm, Wemmershoek.

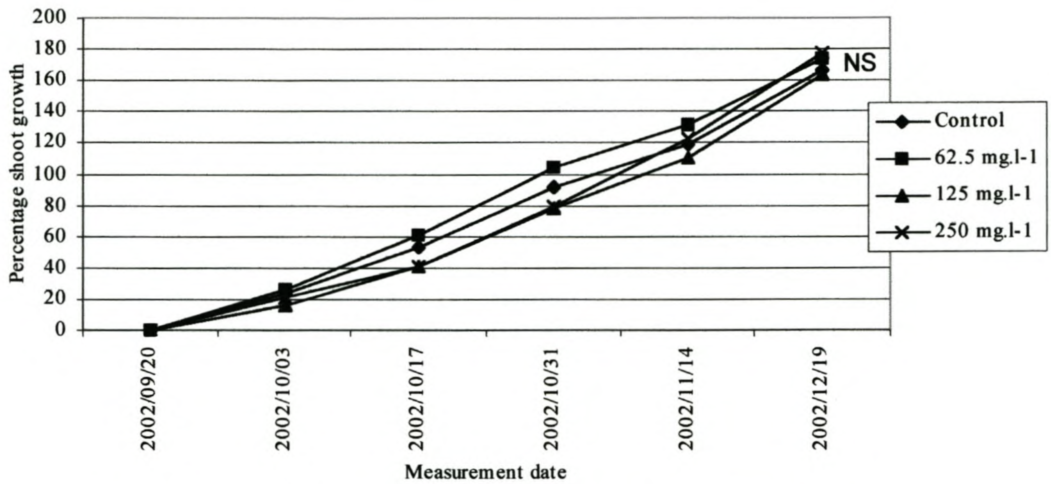

Figure 3. The effect of P-Ca applied at different rates on the shoot growth of 'May Glo' nectarine at Timberlea farm, Stellenbosch.

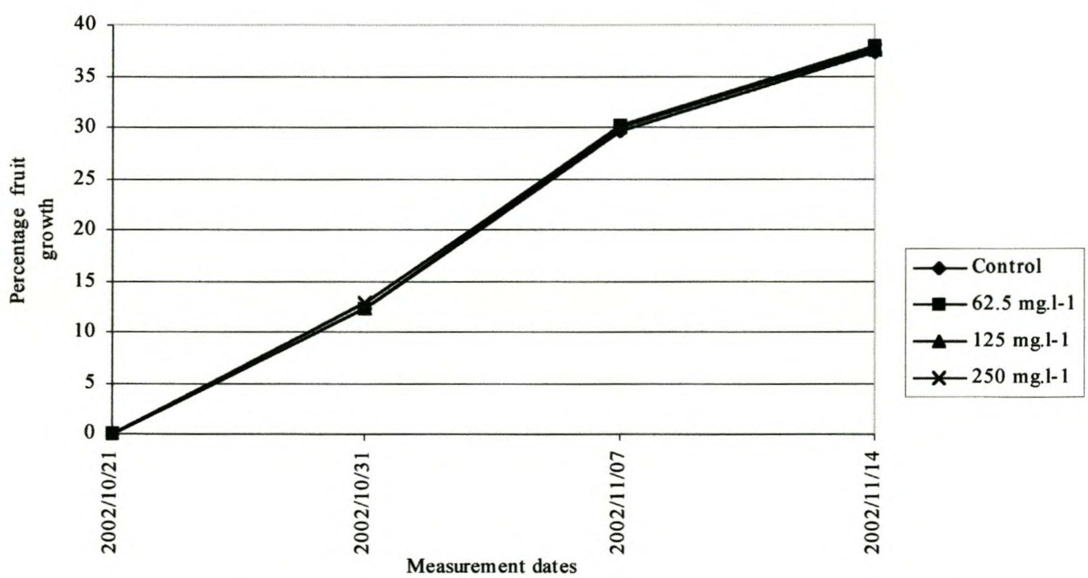

Figure 4. The effect of P-Ca applied at different rates on fruit growth of 'Pioneer' plum at Môrelig farm, Wemmershoek.

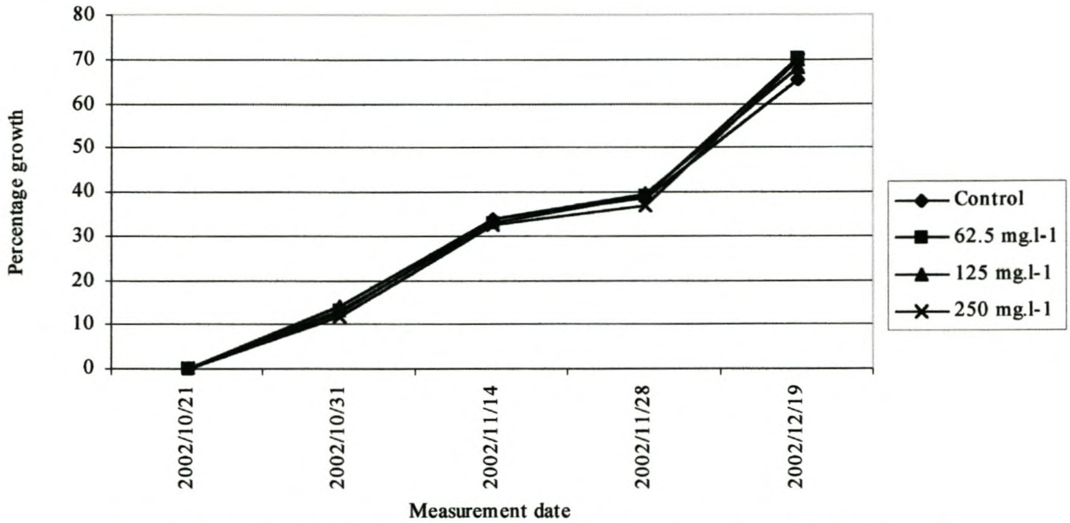

Figure 5. The effect of P-Ca applied at different rates on the fruit growth of 'Songold' plum at Môrelig farm, Wemmershoek.

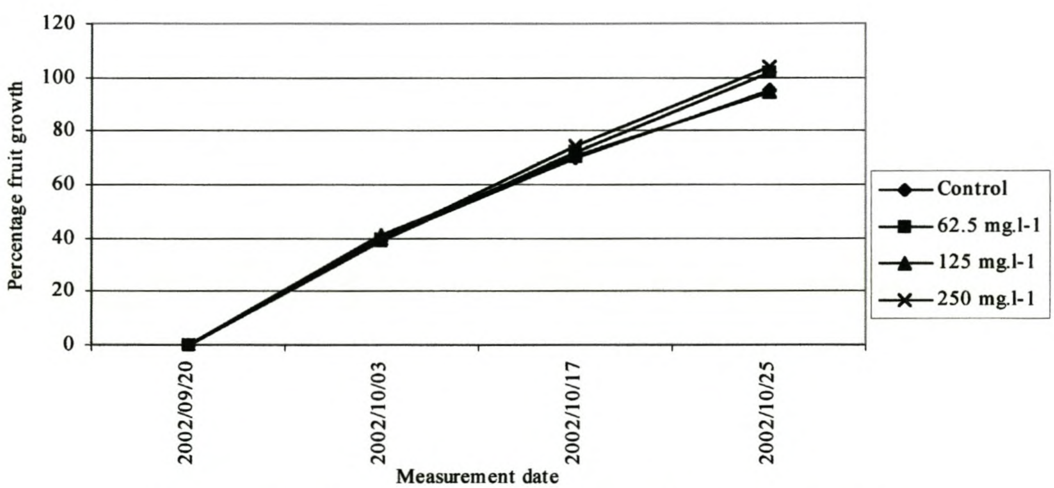

Figure 6. The effect of P-Ca applied at different rates on the fruit growth of 'May Glo' nectarine at Timberlea farm, Stellenbosch.

6. Conclusions

P-Ca reduced shoot growth in apples ('Golden Delicious' and 'Granny Smith'), pears ('Early Bon Chretien', 'Rosemarie', 'Flamingo', 'Forelle' and 'Packham's Triumph') and 'Pioneer' plum. A single application of P-Ca could not provide season-long growth control of 'Songold' plum or 'May Glo' nectarine. Girdling was ineffective at controlling shoot growth of pears, except for 'Forelle' pear.

There was very little regrowth of apple shoots late in the season. It seems that applying P-Ca under conditions favourable for absorption is the main contributing factor to successful shoot growth control. Favourable absorption conditions seemed to nullify the need for a surfactant. If P-Ca is applied when temperature is high and humidity is low, a surfactant should improve absorption and therefore improve the effectiveness of the treatment.

P-Ca improved fruit size of 'Golden Delicious' but not of 'Granny Smith'. Although P-Ca caused a decrease in fruit size of certain pear cultivars, this response was associated with an improved set of these treatments. Girdling caused an increase in fruit size of almost all of the pear cultivars. P-Ca had no effect on fruit size of 'Pioneer'and 'Songold' plums or 'May Glo' nectarine.

Although P-Ca reduced shoot growth, fruit growth was not increased. More research is needed to determine resource allocation when assimilates are not used for shoot growth, in an endeavour to shift the balance of assimilates to cropping.

Further research is required to evaluate the combination of P-Ca and girdling on pear trees. If these two methods could compliment each other, the combination could be a useful tool to reduce shoot growth and, thereby, improve fruit size.

Additional research with P-Ca on stone fruit cultivars is required to determine the correct concentrations and timing of applications.

7. Addendum

Table 1. The effect of girdling and prohexadione-calcium (P-Ca) applied at different rates on the fruit set of 'Flamingo' and 'Packham's Triumph' pear trees at La Plaisante Estate, Wolsely.

	Fruit set / cluster	
Treatments	Flamingo	Packham's Triumph
Control	0.23 a	1.21 a
Girdled	0.26 a	1.18 a
1×125 mg.l^{-1} P-Ca	0.26 a	1.11 a
2×125 mg.l^{-1} P-Ca	0.27 a	1.47 a
1×250 mg.l^{-1} P-Ca	0.31 a	1.37 a
Significance level	*0.8521*	*0.8521*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 2. The effect of girdling and prohexadione-calcium (P-Ca) applied at different rates on the fruit firmness, number of developed seeds and seeds with aborted embryos of 'Early Bon Chretien' pear trees at La Plaisante Estate, Wolsely.

Treatments	Firmness	Seeds (f)	Seeds (d)
Control	10.41 a	0.95 a	8.39 a
Girdled	8.12 a	0.94 a	8.40 a
1×125 mg.l^{-1} P-Ca	8.5 a	0.87 a	8.53 a
2×125 mg.l^{-1} P-Ca	8.43 a	0.77 a	9.05 a
1×250 mg.l^{-1} P-Ca	8.73 a	0.86 a	8.88 a
Significance level	*0.3146*	*0.9592*	*0.5922*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 3. The effect of girdling and prohexadione-calcium (P-Ca) applied at different rates on the fruit firmness, number of developed seeds and seeds with aborted embryos of 'Rosemarie' pear trees at La Plaisante Estate, Wolsely.

Treatments	Firmness	Seeds (f)	Seeds (d)
Control	6.82 a	1.52 a	8.40 a
Girdled	7.07 a	1.23 ab	8.68 a
1×125 mg.l^{-1} P-Ca	7.33 a	1.10 abc	8.85 a
2×125 mg.l^{-1} P-Ca	7.24 a	0.81 bc	9.01 a
1×250 mg.l^{-1} P-Ca	7.17 a	0.51 c	9.23 a
Significance level	*0.1795*	*0.0331*	*0.2054*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 4. The effect of girdling and prohexadione-calcium (P-Ca) applied at different rates on the fruit firmness, number of developed seeds and seeds with aborted embryos of 'Flamingo' pear trees at La Plaisante Estate, Wolsely.

Treatments	Firmness	Seeds (f)	Seeds (d)
Control	6.39 c	1.00 a	8.77 a
Girdled	6.49 bc	0.90 a	8.91 a
1×125 mg.l^{-1} P-Ca	6.75 a	1.40 a	8.28 a
2×125 mg.l^{-1} P-Ca	6.5 bc	1.05 a	8.67 a
1×250 mg.l^{-1} P-Ca	6.67 ab	1.12 a	8.66 a
Significance level	*0.0192*	*0.1662*	*0.1154*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 5. The effect of girdling and prohexadione-calcium (P-Ca) applied at different rates on the fruit firmness, number of developed seeds and seeds with aborted embryos of 'Forelle' pear trees at La Plaisante Estate, Wolsely.

Treatments	Firmness	Seeds (f)	Seeds (d)
Control	6.35 a	0.37 a	8.97 a
Girdled	6.51 a	0.23 a	9.25 a
1×125 mg.l^{-1} P-Ca	6.69 a	0.11 a	8.85 a
2×125 mg.l^{-1} P-Ca	6.41 a	0.28 a	9.19 a
1×250 mg.l^{-1} P-Ca	6.62 a	0.28 a	8.94 a
Significance level	*0.7636*	*0.4035*	*0.6223*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 6. The effect of girdling and prohexadione-calcium (P-Ca) applied at different rates on the fruit firmness, number of developed seeds and seeds with aborted embryos of 'Packham's Triumph' pear trees at La Plaisante Estate, Wolsely.

Treatments	Firmness	Seeds (f)	Seeds (d)
Control	7.14 a	0.39 a	9.11 a
Girdled	7.00 a	0.43 a	9.04 ab
1×125 mg.l^{-1} P-Ca	7.19 a	0.39 a	8.29 abc
2×125 mg.l^{-1} P-Ca	7.18 a	0.43 a	8.26 bc
1×250 mg.l^{-1} P-Ca	7.11 a	0.52 a	7.66 c
Significance level	*0.8062*	*0.9478*	*0.0058*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 7. The effect of prohexadione-calcium (P-Ca) applied at different rates on the number of developed seeds, seeds with aborted embryos and the fruit set of 'Golden Delicious' apple trees on High Noon farm, Villiersdorp (Trial 1).

Treatments	Seeds(f)	Seeds(d)	Fruit set
Control	6.58 a	0.07 a	0.72 ab
Previously unsprayed	6.58 a	0.05 a	0.63 b
4×67 $mg.l^{-1}$ P-Ca	6.44 a	0.13 a	0.69 ab
4×67 $mg.l^{-1}$ P-Ca+ Dash®	6.20 a	0.13 a	1.14 a
Significance level	*0.4342*	*0.6094*	*0.1309*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 8. The effect of prohexadione-calcium (P-Ca) applied at different rates on the severity of russet and ground colour development of 'Golden Delicious' apple trees on High Noon farm, Villiersdorp (Trial 1).

Treatments	Russet	Ground colour
Control	2.13 a	3.15 b
Previously unsprayed	1.81 ab	3.13 b
4×67 $mg.l^{-1}$ P-Ca	1.57 b	3.20 ab
4×67 $mg.l^{-1}$ P-Ca+ Dash®	1.62 ab	3.35 a
Significance level	*0.1287*	*0.1036*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 9. The effect of prohexadione-calcium (P-Ca) applied at different rates on the number of developed seeds, seeds with aborted embryos and the fruit set of 'Granny Smith' apple trees on High Noon farm, Villiersdorp (Trial 1).

Treatments	Seeds(f)	Seeds(d)	Fruit set
Control	6.60 a	0.38 a	0.43 a
Previously unsprayed	6.89 a	0.18 a	0.52 a
4×67 $mg.l^{-1}$ P-Ca	6.46 a	0.45 a	0.43 a
4×67 $mg.l^{-1}$ P-Ca+ Dash®	6.53 a	0.35 a	0.51 a
Significance level	*0.2714*	*0.3084*	*0.7194*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 10. The effect of prohexadione-calcium (P-Ca) applied at different rates on the severity of russet and ground colour development of 'Granny Smith' apple trees on High Noon farm, Villiersdorp (Trial 1).

Treatments	Russet	Ground colour
Control	1.16 a	1.57 a
Previously unsprayed	0.66 b	1.66 a
4×67 $mg.l^{-1}$ P-Ca	0.79 b	1.56 a
4×67 $mg.l^{-1}$ P-Ca+ Dash®	0.70 b	1.26 b
Significance level	*0.0096*	*0.0308*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 11. The effect of prohexadione-calcium (P-Ca) applied at different rates on the number of developed seeds, seeds with aborted embryos and the fruit set of 'Golden Delicious' apple trees on High Noon farm, Villiersdorp (Trial 2).

Treatments	Seeds (f)	Seeds (d)	Fruit set
Control	5.33 ab	0.07 ab	1.63 a
1×67 $mg.l^{-1}$ P-Ca	5.45 ab	0.07 ab	1.64 a
1×67 $mg.l^{-1}$ P-Ca+ Dash®	5.16 b	0.06 ab	1.29 a
2×67 $mg.l^{-1}$ P-Ca	5.49 ab	0.07 ab	1.61 a
2×67 $mg.l^{-1}$ P-Ca+ Dash®	5.49 ab	0.09 ab	1.37 a
3×67 $mg.l^{-1}$ P-Ca	5.66 a	0.07 ab	1.48 a
3×67 $mg.l^{-1}$ P-Ca+ Dash®	5.16 b	0.05 b	1.63 a
4×67 $mg.l^{-1}$ P-Ca	5.43 ab	0.07 ab	1.57 a
4×67 $mg.l^{-1}$ P-Ca+ Dash®	5.41 ab	0.49 a	1.71 a
Significance level	*0.4759*	*0.5743*	*0.7035*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 12. The effect of prohexadione-calcium (P-Ca) applied at different rates on the severity of russet and ground colour development of 'Golden Delicious' apple trees on High Noon farm, Villiersdorp (Trial 2).

Treatments	Russet	Ground colour
Control	2.01 a	3.11 a
1×67 $mg.l^{-1}$ P-Ca	2.14 a	3.20 a
1×67 $mg.l^{-1}$ P-Ca+ Dash®	2.02 a	3.26 a
2×67 $mg.l^{-1}$ P-Ca	2.28 a	3.29 a
2×67 $mg.l^{-1}$ P-Ca+ Dash®	2.06 a	3.15 a
3×67 $mg.l^{-1}$ P-Ca	2.17 a	3.14 a
3×67 $mg.l^{-1}$ P-Ca+ Dash®	2.04 a	3.19 a
4×67 $mg.l^{-1}$ P-Ca	2.36 a	3.30 a
4×67 $mg.l^{-1}$ P-Ca+ Dash®	1.97 a	3.10 a
Significance level	*0.9154*	0.5046

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 13. The effect of prohexadione-calcium (P-Ca) applied at different rates on the number of developed seeds, seeds with aborted embryos and the fruit set of 'Granny Smith' apple trees on High Noon farm, Villiersdorp (Trial 2).

Treatments	Seeds(f)	Seeds(d)	Fruit set
Control	6.61 a	0.41 a	0.83 ab
1×67 $mg.l^{-1}$ P-Ca	6.64 a	0.30 a	0.82 ab
1×67 $mg.l^{-1}$ P-Ca+ Dash®	6.42 a	0.34 a	0.70 ab
2×67 $mg.l^{-1}$ P-Ca	6.68 a	0.39 a	0.96 a
2×67 $mg.l^{-1}$ P-Ca+ Dash®	6.29 a	0.45 a	0.75 ab
3×67 $mg.l^{-1}$ P-Ca	6.60 a	0.29 a	0.76 ab
3×67 $mg.l^{-1}$ P-Ca+ Dash®	6.55 a	0.24 a	0.88 ab
4×67 $mg.l^{-1}$ Pr-Ca	6.13 a	0.33 a	0.60 b
4×67 $mg.l^{-1}$ P-Ca+ Dash®	6.59 a	0.33 a	0.60 b
Significance level	*0.7728*	*0.9824*	*0.3803*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 14. The effect of prohexadione-calcium (P-Ca) applied at different rates on the severity of russet and ground colour development of 'Granny Smith' apple trees on High Noon farm, Villiersdorp (Trial 2).

Treatments	Russet	Ground colour
Control	0.84 a	1.58 a
1×67 mg.l^{-1} P-Ca	0.76 a	1.56 a
1×67 mg.l^{-1} P-Ca + Dash®	0.85 a	1.50 a
2×67 mg.l^{-1} P-Ca	0.94 a	1.52 a
2×67 mg.l^{-1} P-Ca+ Dash®	0.94 a	1.69 a
3×67 mg.l^{-1} P-Ca	0.92 a	1.57 a
3×67 mg.l^{-1} P-Ca+ Dash®	0.87 a	1.65 a
4×67 mg.l^{-1} P-Ca	0.90 a	1.67 a
4×67 mg.l^{-1} P-Ca+ Dash®	0.91 a	1.59 a
Significance level	*0.9955*	*0.9358*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 15. The effect of prohexadione-calcium (P-Ca) applied at different rates on the fruit firmness, Brix and occurrence of split pit of 'Pioneer' plum trees on Môrelig farm, Wemmershoek.

Treatments	Firmness	°Brix	Split pit
Control	7.86 a	10.24 a	0.095 a
1×62.5 mg.l^{-1} P-Ca	8.35 b	10.50 a	0.080 a
1×125 mg.l^{-1} P-Ca	8.62 b	10.20 a	0.105 a
1×250 mg.l^{-1} P-Ca	8.45 b	10.38 a	0.095 a
Significance level	*0.0031*	*0.3169*	*0.8826*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 16. The effect of prohexadione-calcium (P-Ca) applied at different rates on the fruit firmness, Brix and occurrence of split pit of 'Songold' plum trees on Môrelig farm, Wemmershoek.

Treatments	Firmness	°Brix	Split pit
Control	6.54 a	12.86 a	0.11 a
1×62.5 $mg.l^{-1}$ P-Ca	6.36 a	12.60 a	0.11 a
1×125 $mg.l^{-1}$ P-Ca	6.71 a	12.46 a	0.20 a
1×250 $mg.l^{-1}$ P-Ca	6.90 a	12.20 a	0.13 a
Significance level	*0.3948*	*0.0394*	*0.1113*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.

Table 17. The effect of prohexadione-calcium (P-Ca) applied at different rates on the fruit firmness, Brix and occurrence of split pit of 'May Glo' plums on Timberlea farm, Stellenbosch.

Treatments	Firmness	°Brix	Split pit
Control	10.10 a	8.09 a	8.4 a
1×62.5 $mg.l^{-1}$ P-Ca	10.31 a	7.72 a	6.6 ab
1×125 $mg.l^{-1}$ P-Ca	9.83 a	7.88 a	4.3 bc
1×250 $mg.l^{-1}$ P-Ca	9.88 a	7.84 a	3.6 c
Significance level	*0.2776*	*0.2794*	*0.0109*

According to the LSD method, means with the same letter are not significantly different at the 5 % confidence level.